Nanostructure

- Materials Growth
- Characterization
- Fabrication

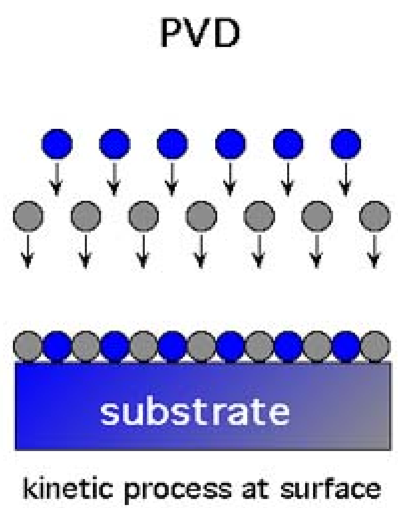
More see Waser, chapter 2

Materials growth - deposition

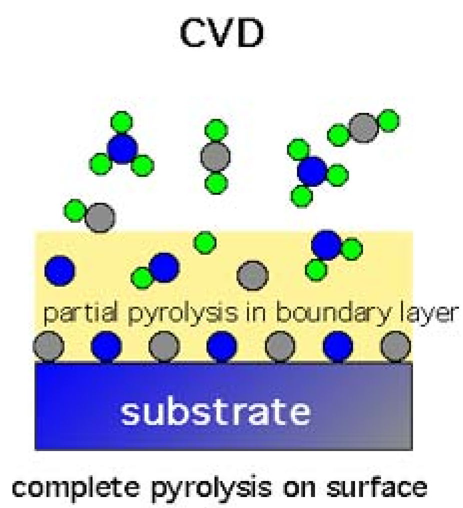
deposition

gas → solid

Physical Vapor Deposition



Chemical Vapor Deposition



Physical Vapor Deposition

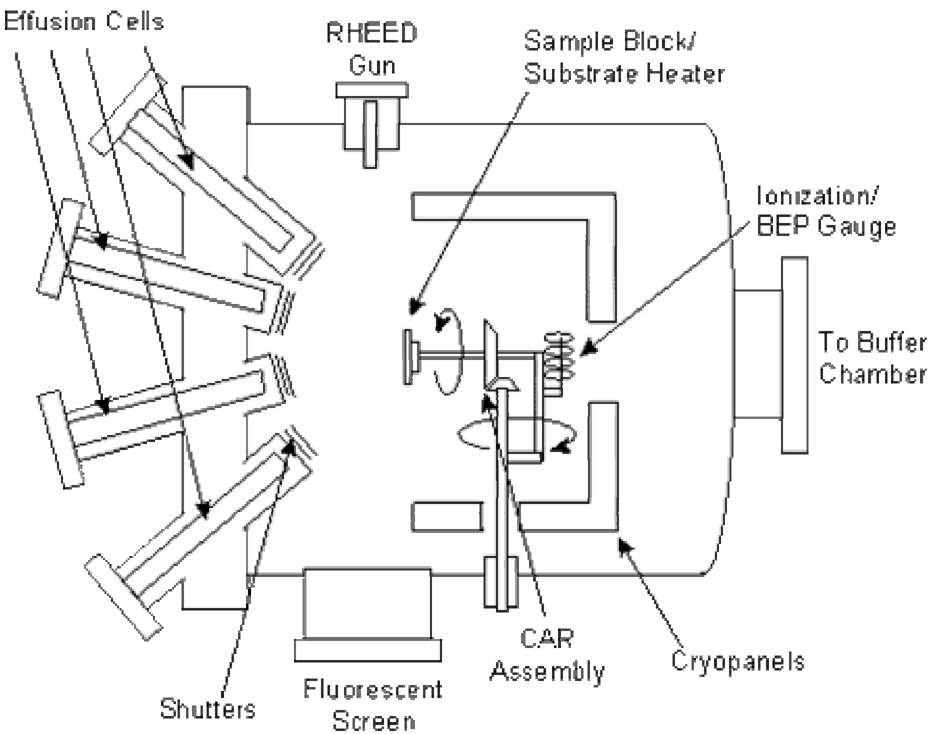
- vacuum evaporation
- sputtering
- molecular beam epitaxy (MBE)

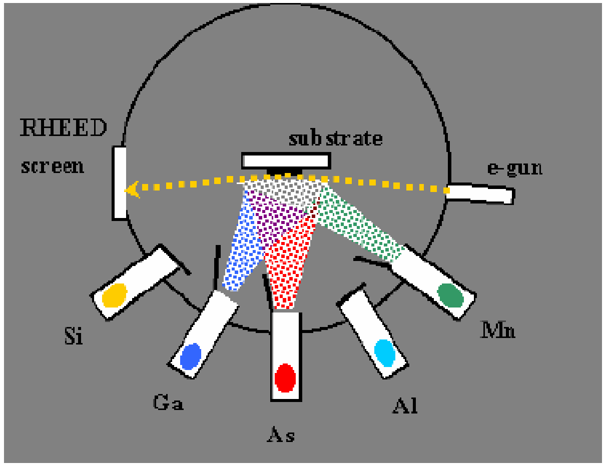
Chemical Vapor Deposition

- atmospheric pressure chemical vapor deposition (APCVD)
- low pressure chemical vapor deposition (LPCVD)
- plasma assisted (enhanced) chemical vapor deposition (PACVD, PECVD)
- photochemical vapor deposition (PCVD)
- laser chemical vapor deposition (LCVD)
- metal-organic chemical vapor deposition (MOCVD)
- chemical beam epitaxy (CBE)

Molecular Beam Epitaxy (MBE)

MBE chamber





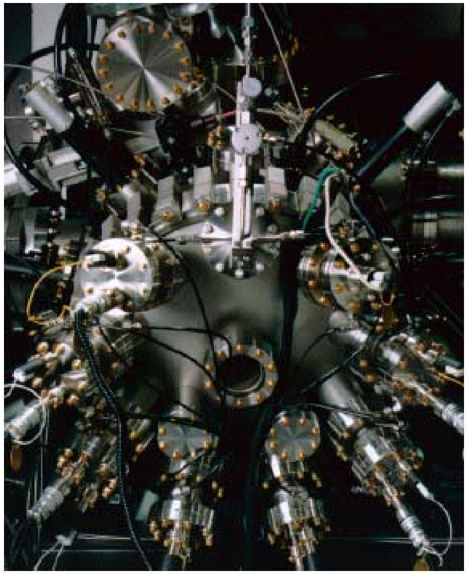
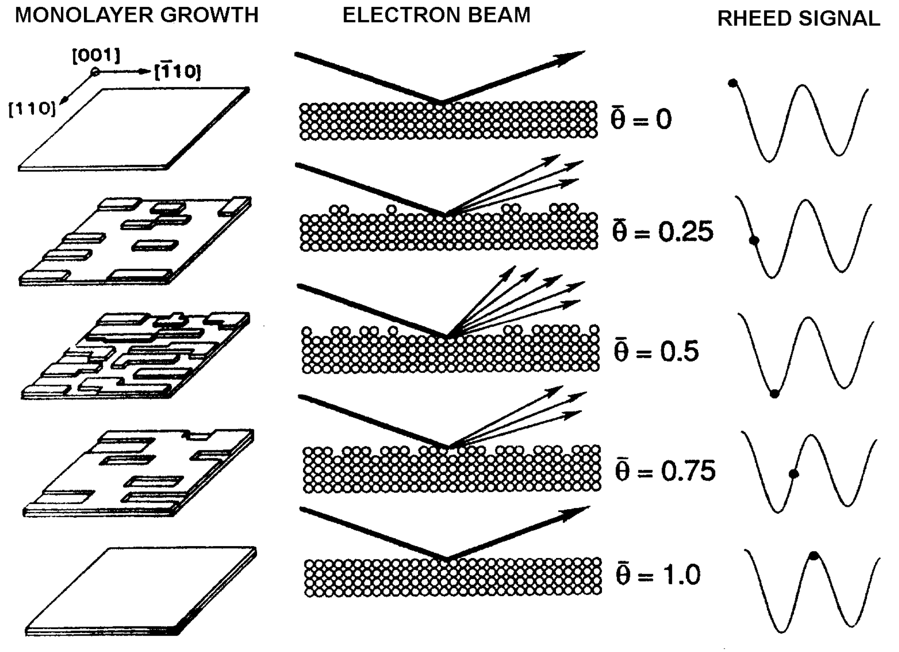
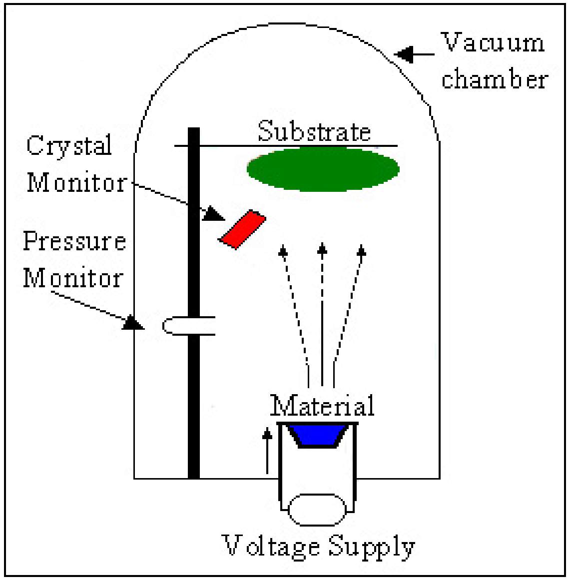


Image from Schlom at PSU.

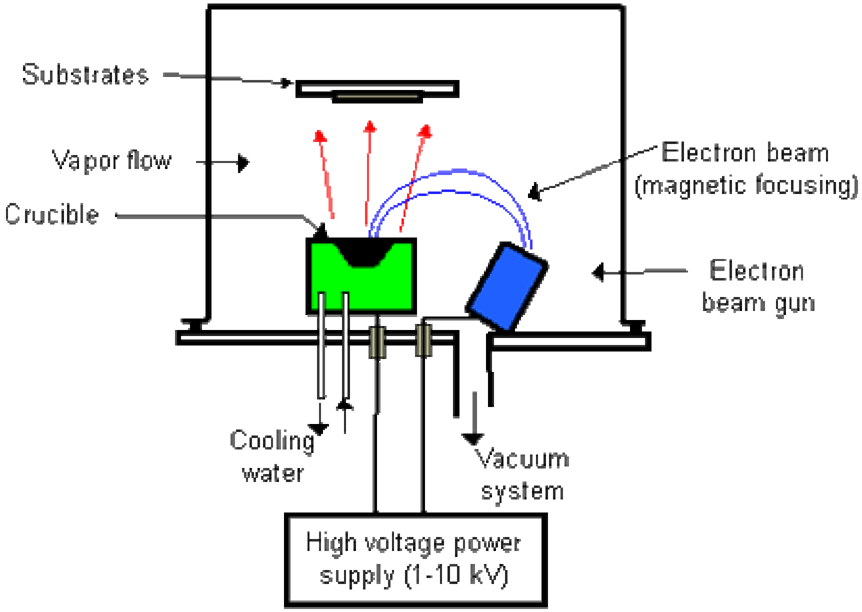
RHEED monitoring the film quality



vacuum evaporation

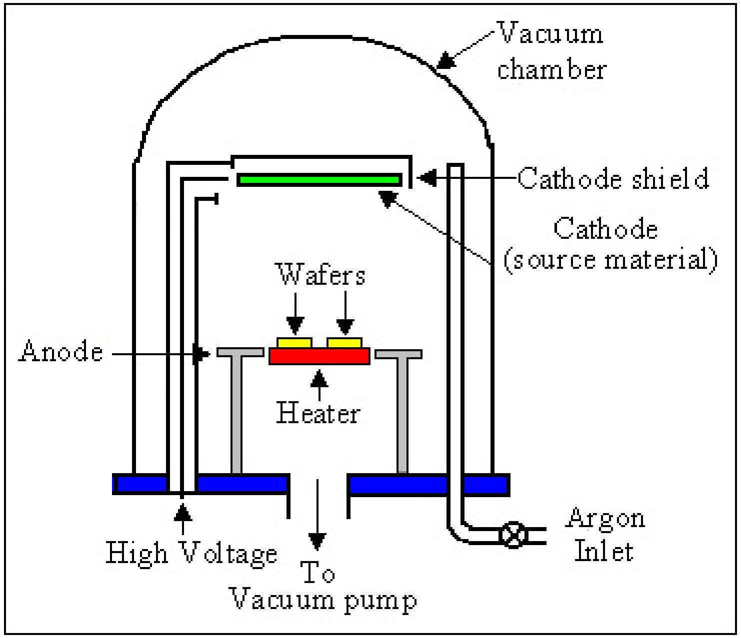


Thermal evaporation



e-beam evaporation

Sputtering



Sample at cathode

Target at Anode and bombarded by high energy ions generated by a plasma discharge

Sputtering vs. evaporation

- Higher energy with sputtering produces higher packing densities and better adhesion if stresses are low.

- Greater variety of materials including alloys and mixtures can be sputtered than evaporated.

- Depositions can be made on temperature-sensitive substrates such as polymers.

- Deposition rates are lower for sputtering than for e-beam, but stresses can be higher.

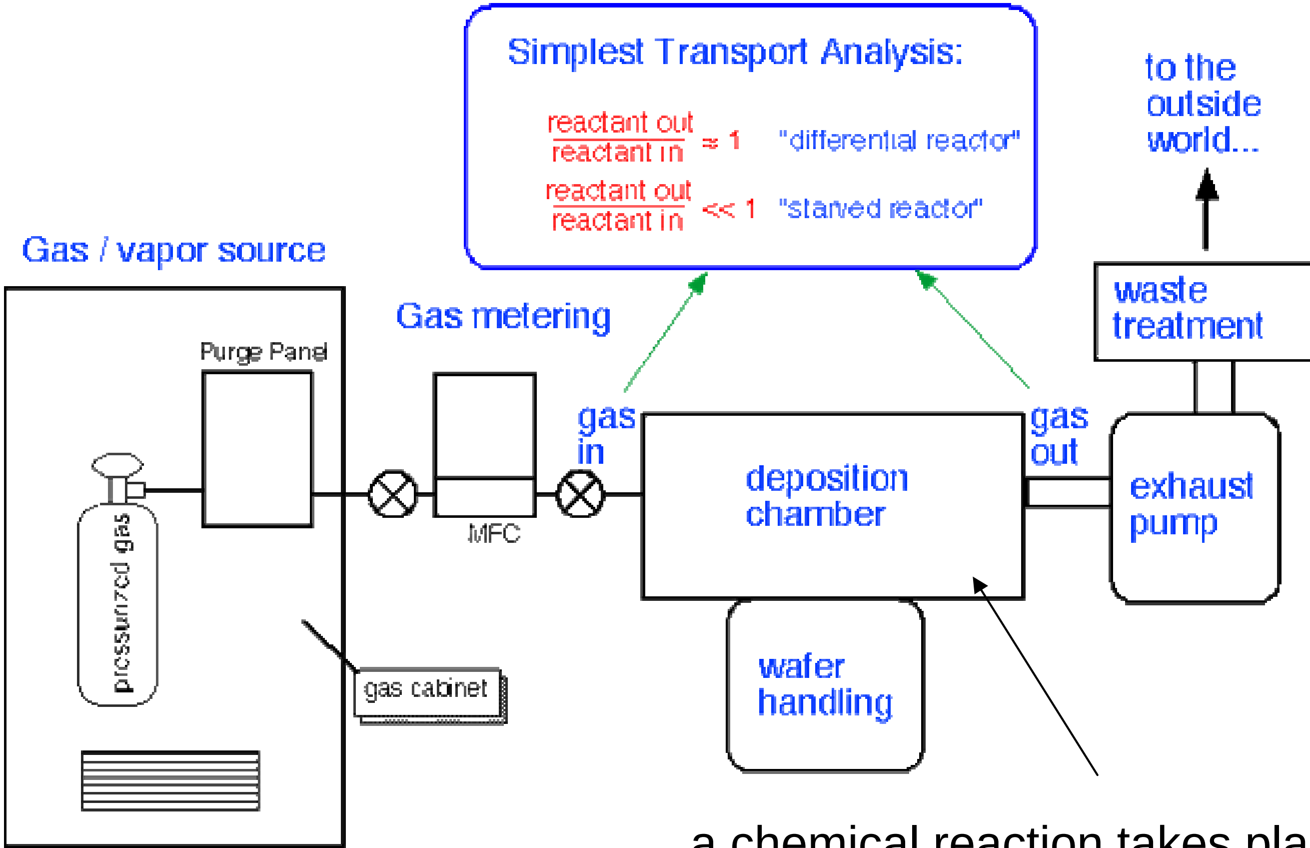
- Sputtering provides better step coverage, while evaporation is more directional.

- Sputter equipment is more expensive.

- Sputtering optical multi-layers is more difficult.

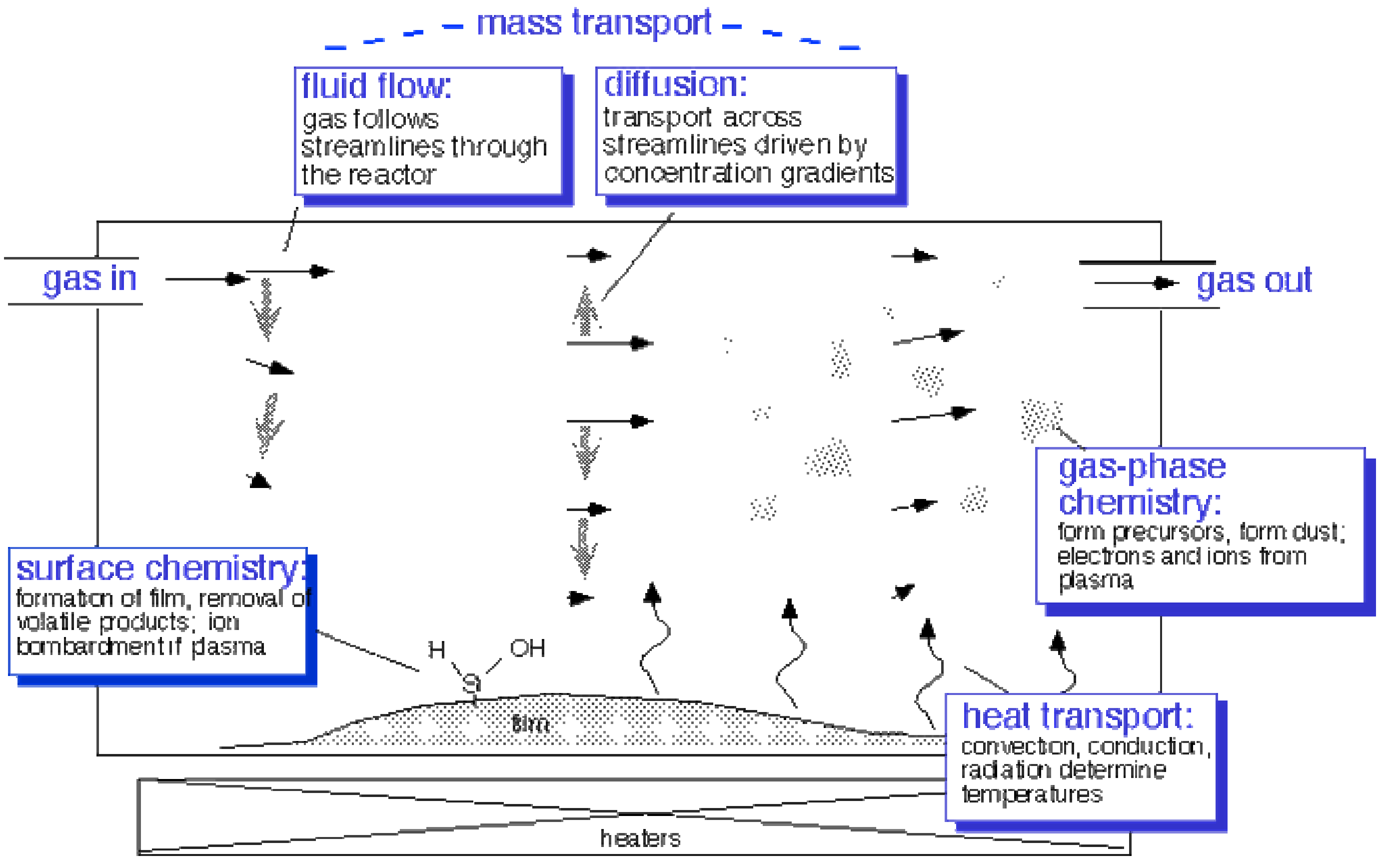
- Sputtering involves a greater number of process variables than evaporation, but many of them are stable and repeatable, permitting sputtering to be automated.

Chemical Vapor Deposition (CVD)



a chemical reaction takes place between the source gases (precursors)

Chemical Vapor Deposition (CVD)



Gas measurement and metering
Transport of molecules by gas flow and diffusion
Transport of heat by convection, conduction, and radiation
Chemical reactions in the gas phase and at the surfaces
Plasma formation and behavior
Characterization of the resulting films

CVD vs. PVD

pros

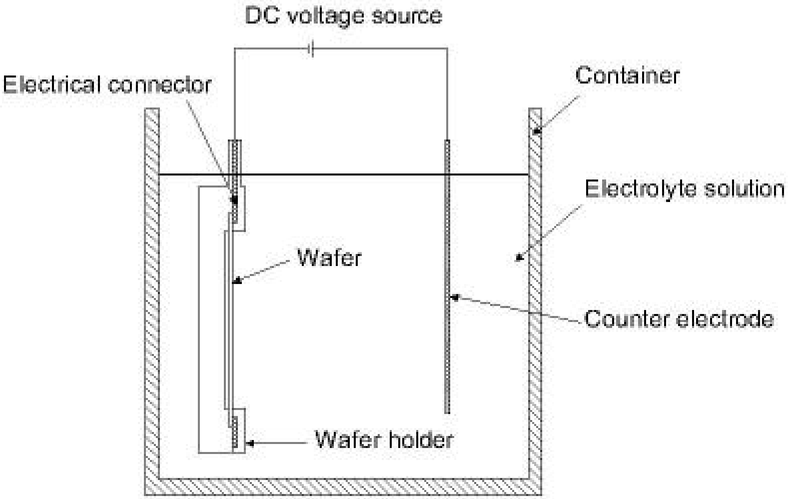
- ***Excellent Step coverage***
- ***Uniform distribution over large areas***
- ***No compositional gradients across substrate***
- ***No need to break vacuum for source changes***
- ***More selective area deposition because of higher activation energy for reaction with foreign substances.***

cons

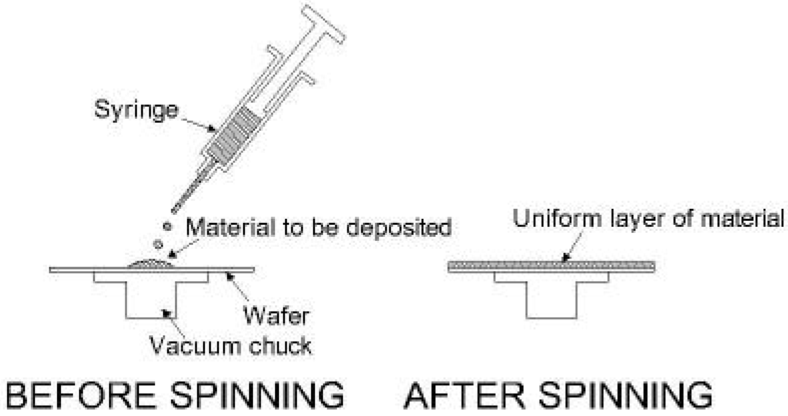
- ***Mostly involve safety and contamination***
- ***Hydrides and carbonyls are poisonous (especially arsine)***
- ***Metalorganics are pyrophoric (ignite in contact with air)***
- ***High cost for compounds with sufficient purity***

Other thin film "growth" techniques

electroplating



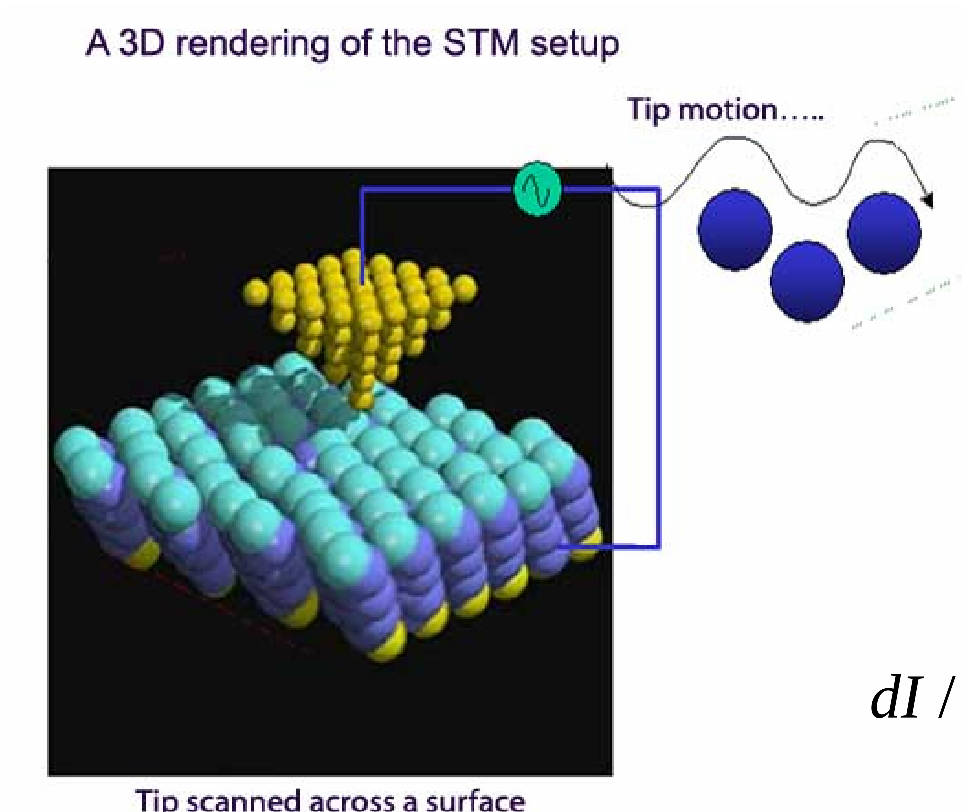
Spin coating

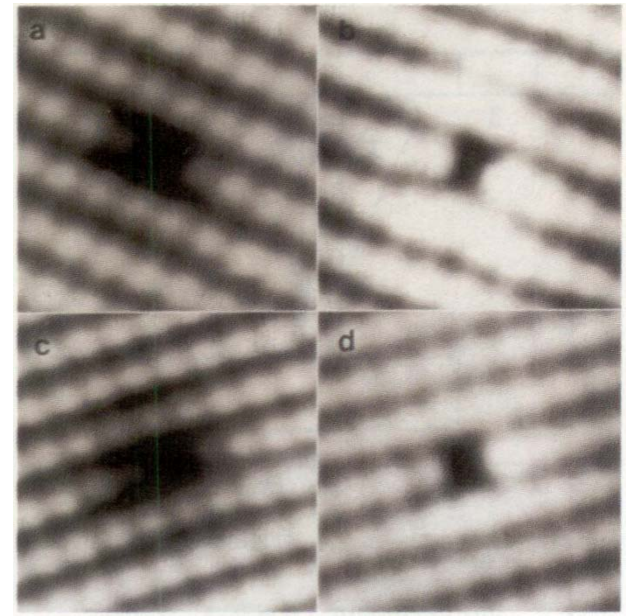


Materials Characterization Techniques

- Scanning Tunneling Microscope (STM)
- Transmission Electron Microscope (TEM)
- Scanning Electron Microscope (SEM)
- Atomic Force Microscope (AFM)
  and Scanning Probe Microscope (SPM) in general

Scanning Tunneling Microscope (STM)



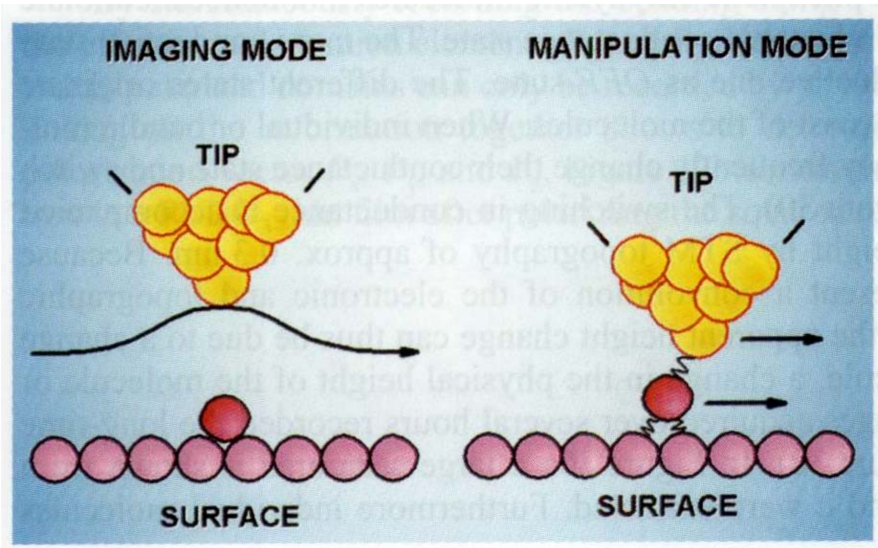


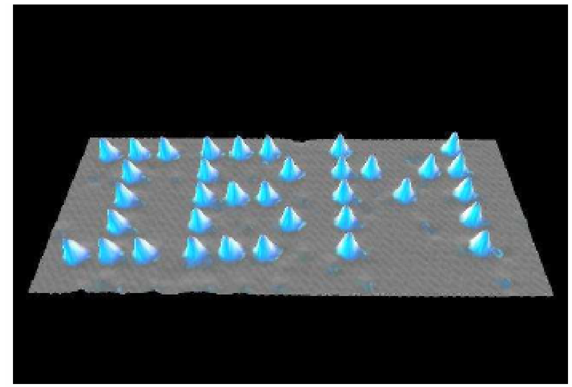
$$dI/dV \propto \Gamma D_{sample}(E) D_{tip}(E+eV)$$

$$\Gamma \propto e^{-2kd}$$

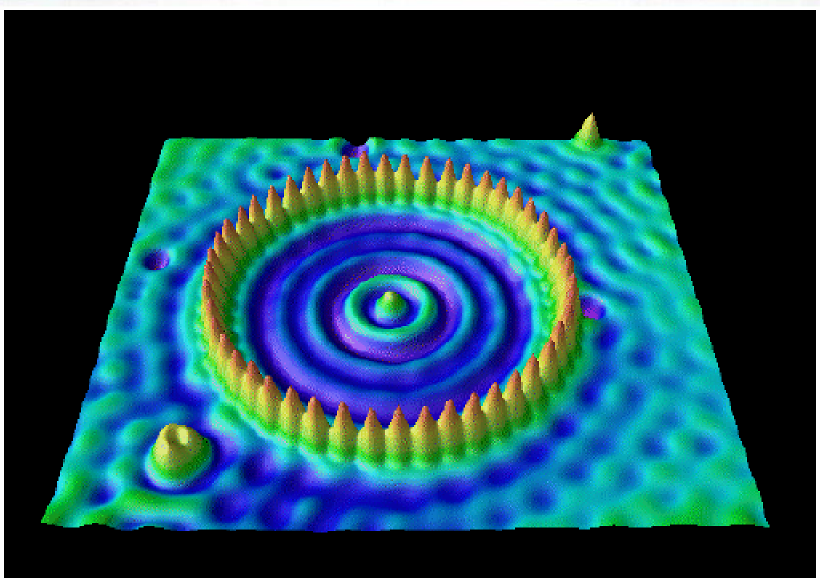
Measures the tunneling current. topographic information abstained from the feedback signal in *constant current* mode.

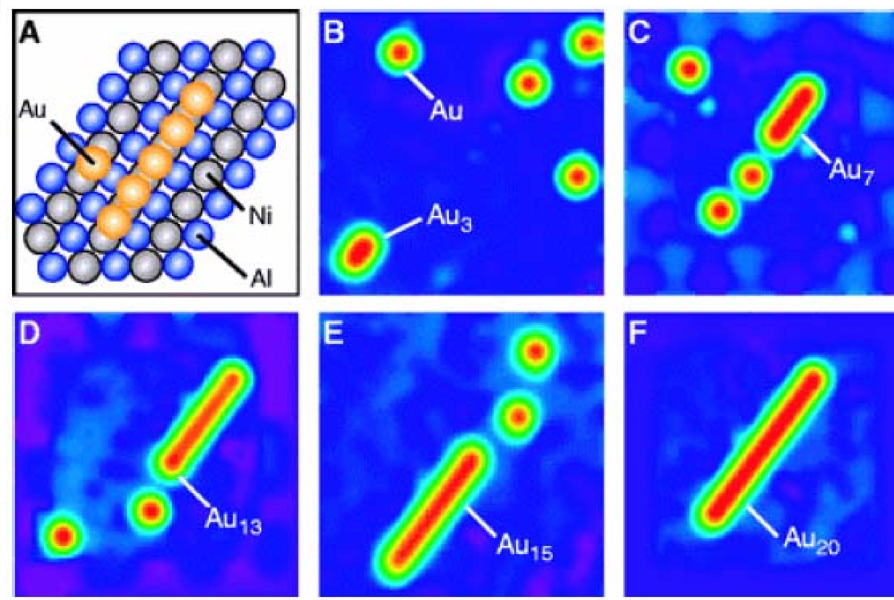
Scanning Tunneling Microscope (STM)
Manipulate individual atoms



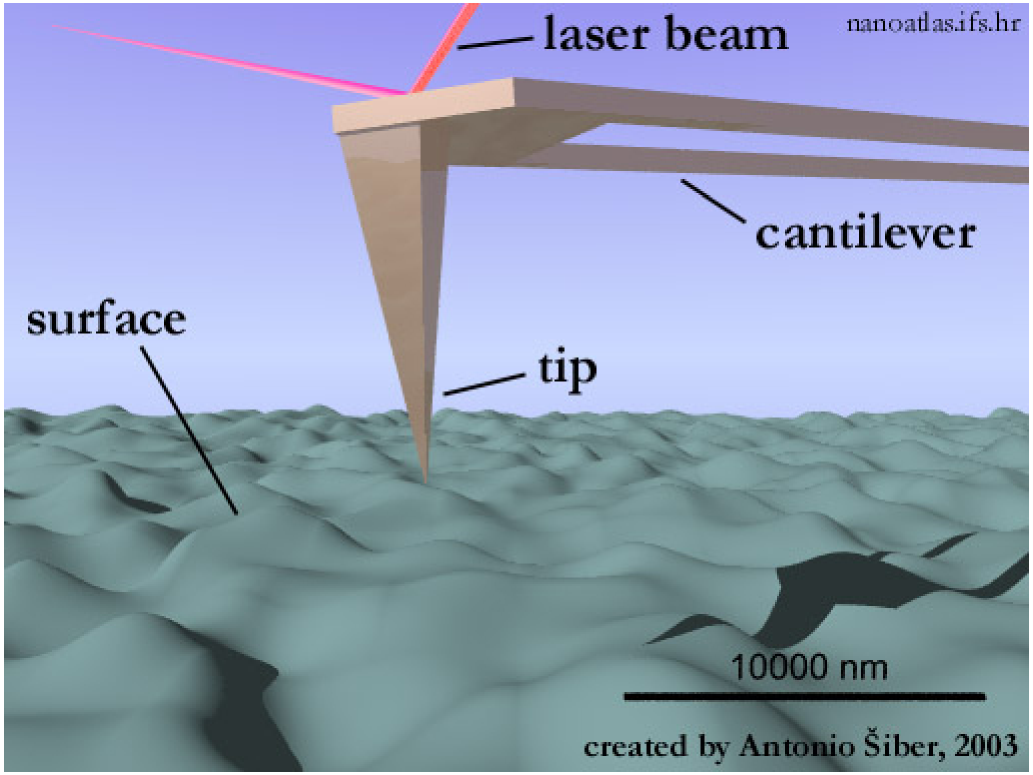


Images from Eigler at IBM.



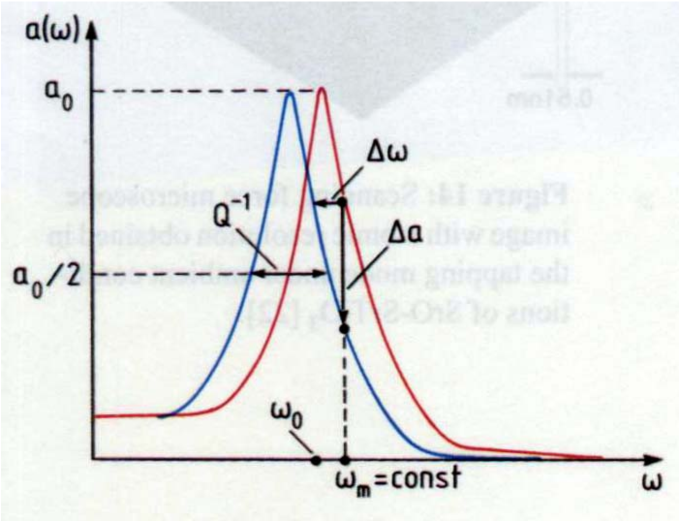


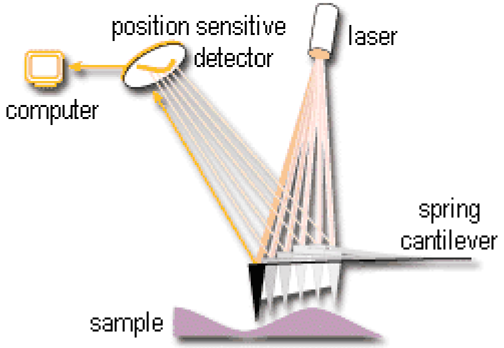
Atomic Force Microscope (AFM)



Non-contactmode:
Van der Waals, electrostatic, magnetic or capillary forces

Contact mode:
Ionic repulsion forces

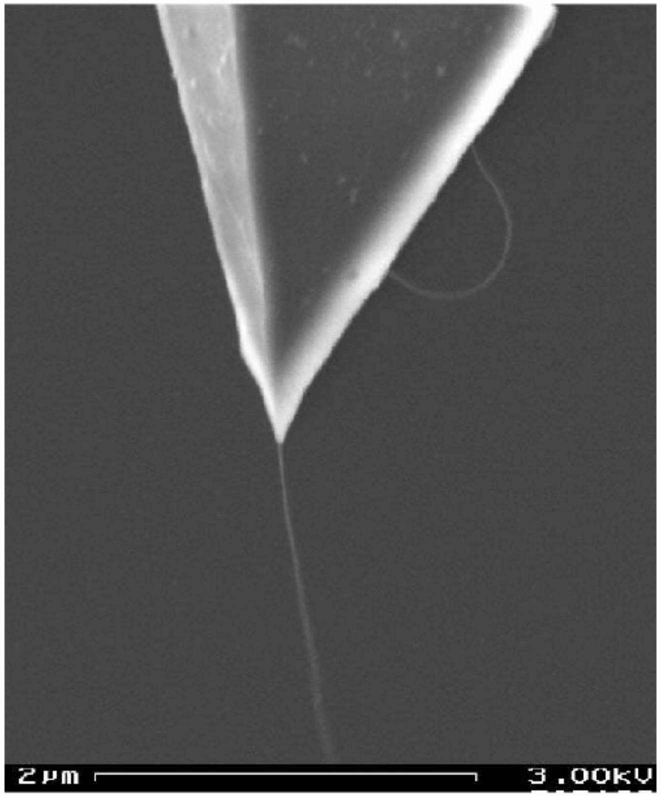




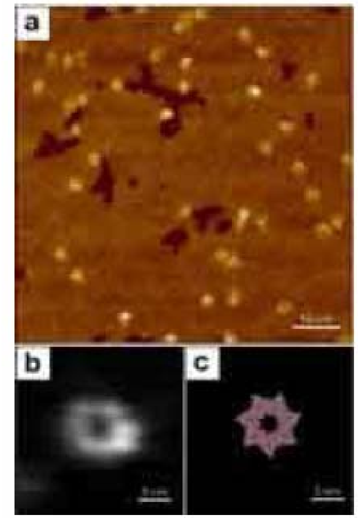
Dynamic contact (taping mode): Amplitude decreases at fixed frequency

Feedback loop keeps the amplitude constant. Signal from the feedback loop reflects *force* information, which depends on the materials, etc, and can be converted to *height* information.

Atomic Force Microscope (AFM)

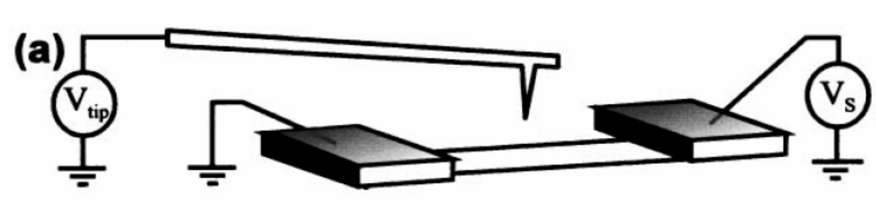


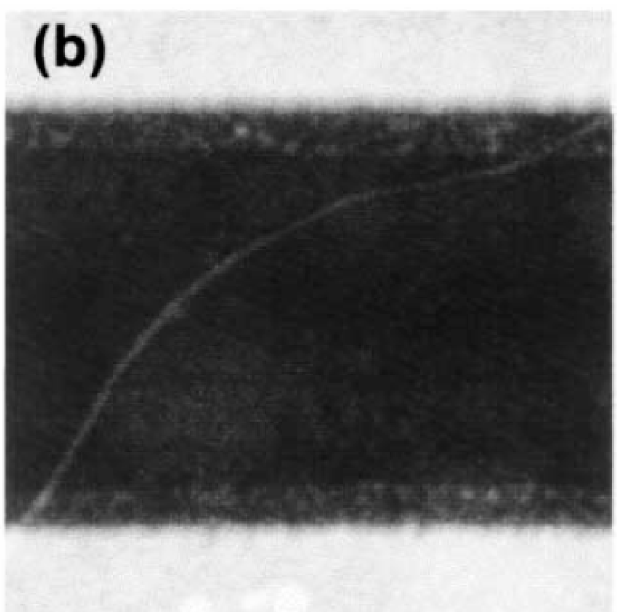
Images from Hafner and Lieber.



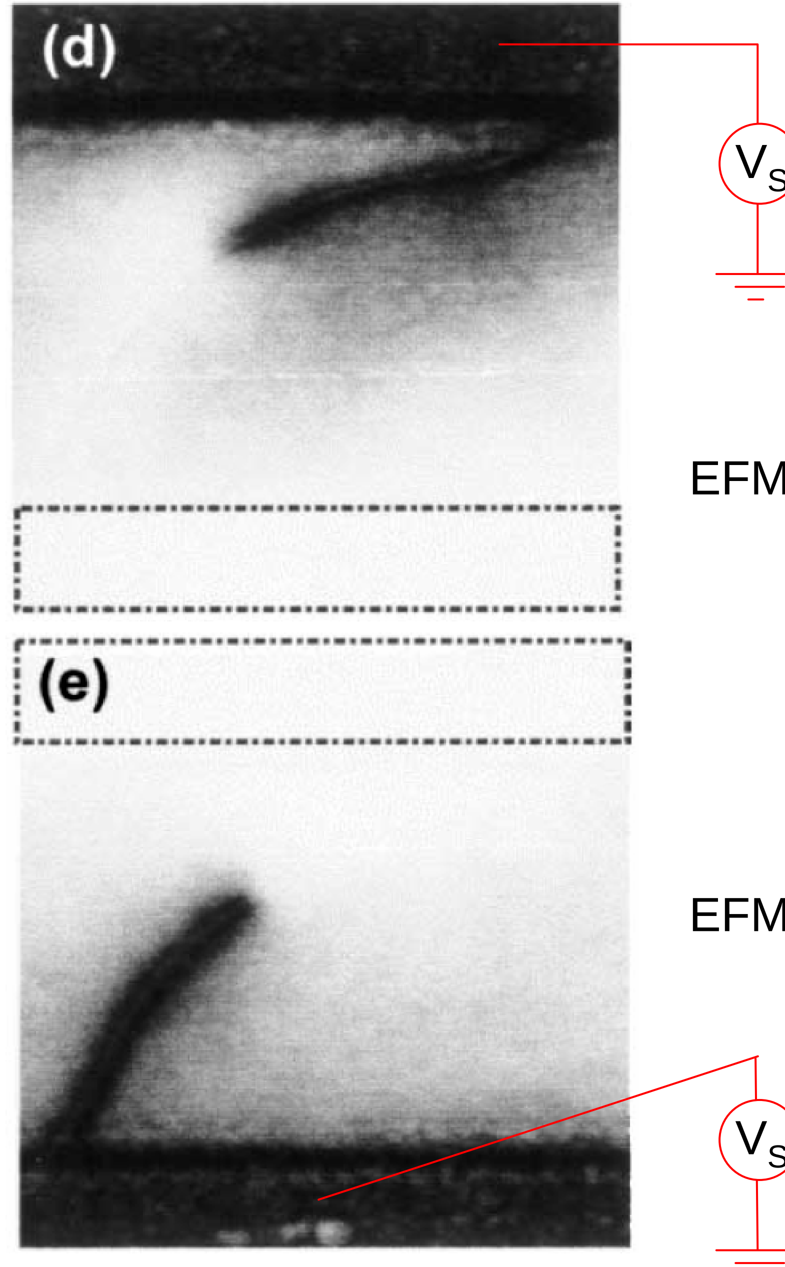
- AFM allows imaging of surface topography with subnm *hight* resolution, and lateral resolution limited by radius of curvature of tip.
- resolution ~ 1nm is possible with smaller, eg, carbon nanotube tips,!

Electrostatic Scanning Force Microscopy (EFM)

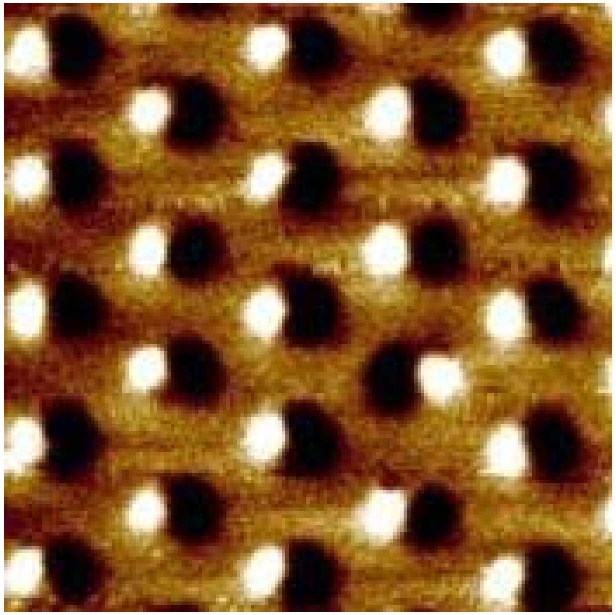




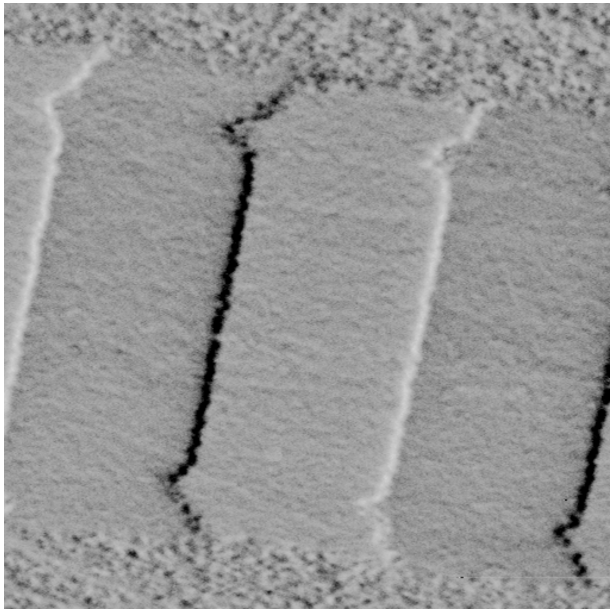
Topographic AFM image



Magnetic Force Microscope (MFM)

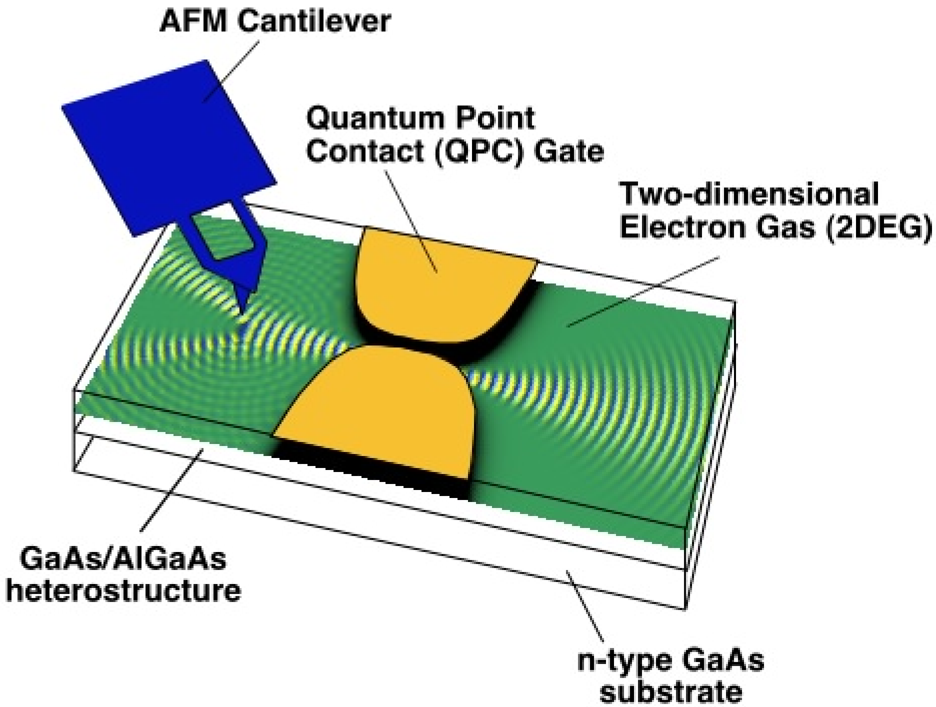


MFM image of nanomagnets.
Bright area (north pole)
Dark area (south pole)

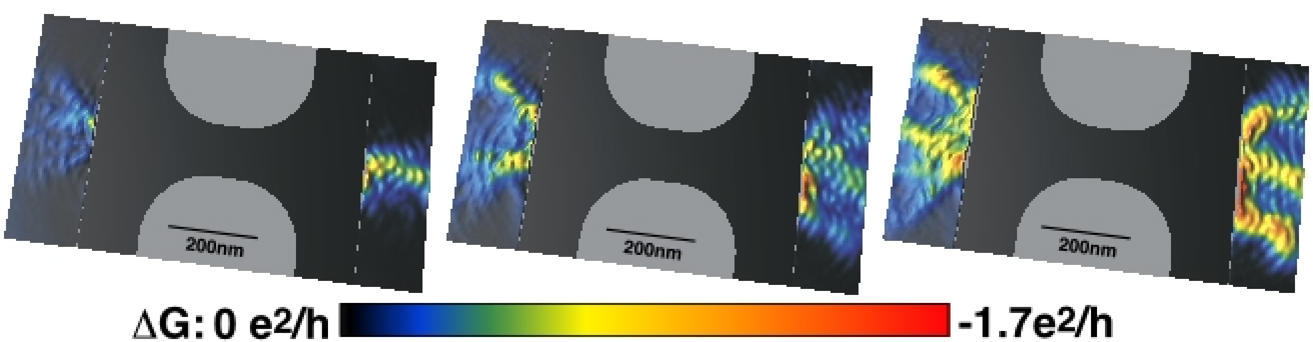


MFM image of recorded bits on thin-film disk recording media. The region imaged is 15x15 micrometers in dimension.

Scanning Gate Method

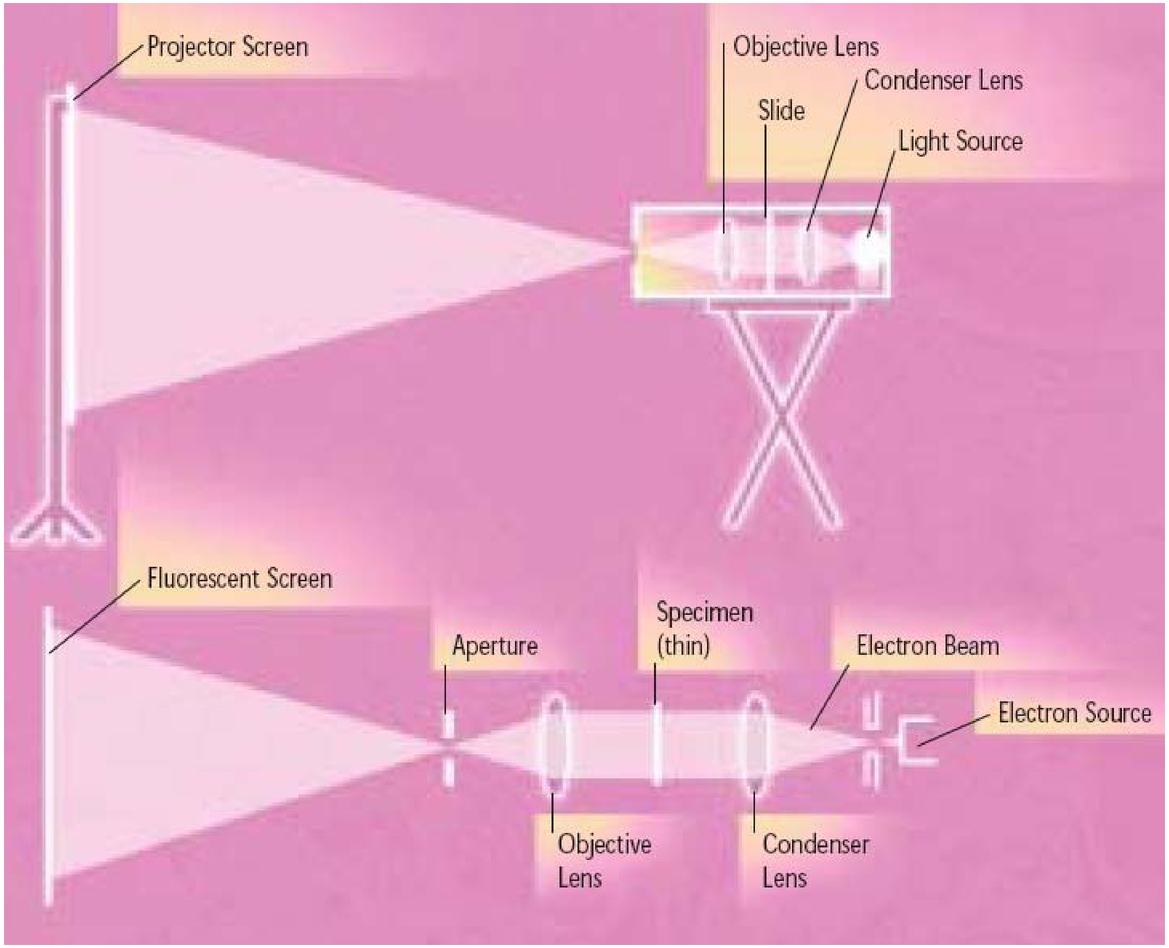


Charged AFM tip acts as a mobile gate.
Changes in current measured simultaneously at each position.



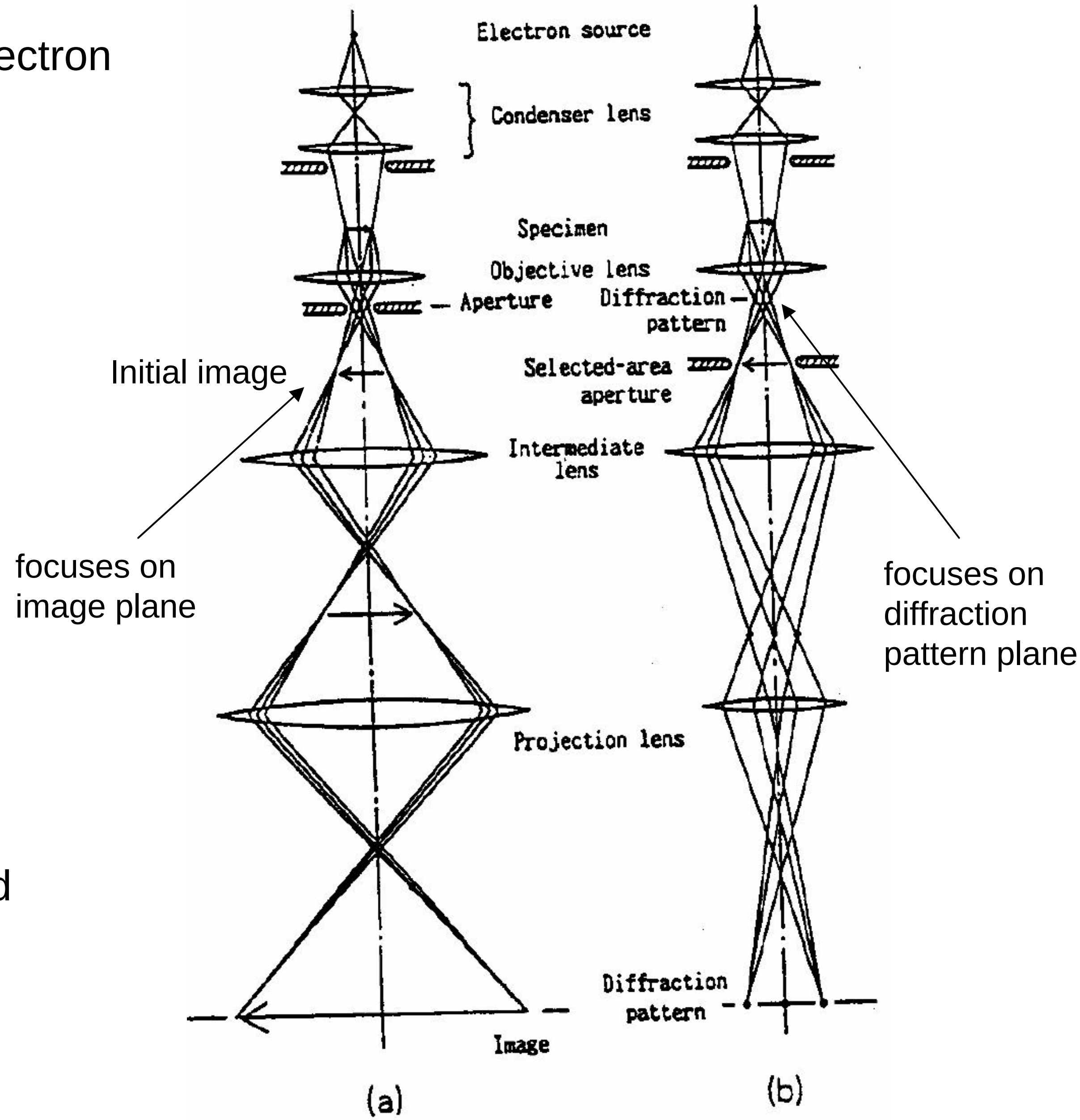
Westervelt group at Harvard

Transmission electron microscope (TEM)



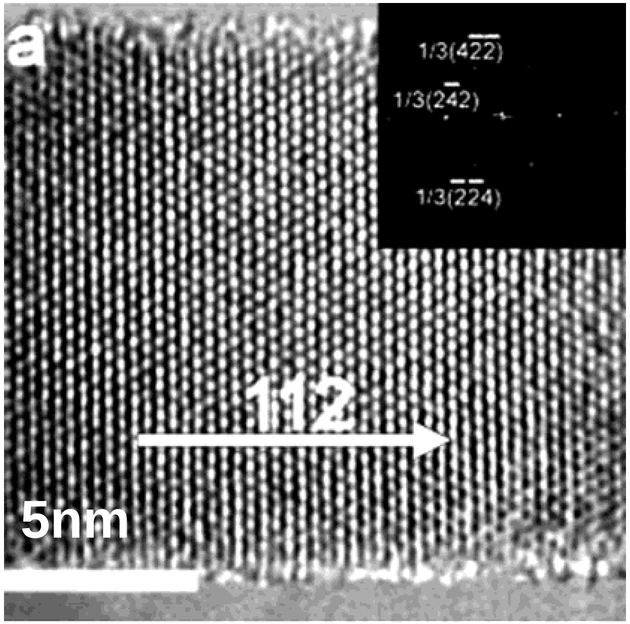
Comparison between a TEM and a slide projector.

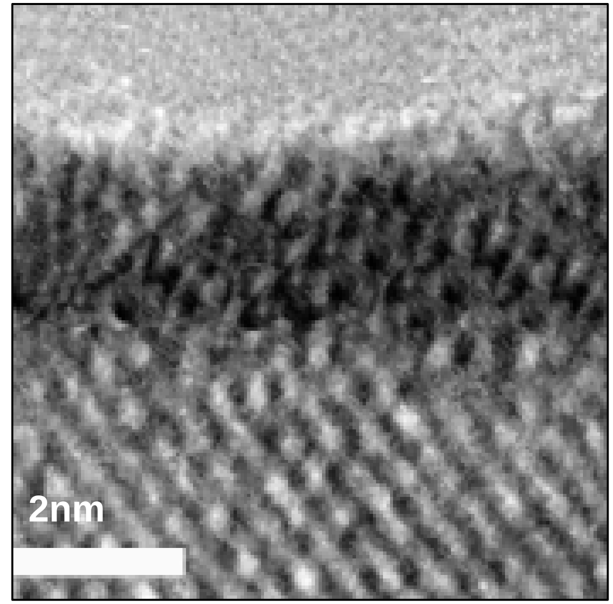
(Bright field) imaging vs. electron diffraction

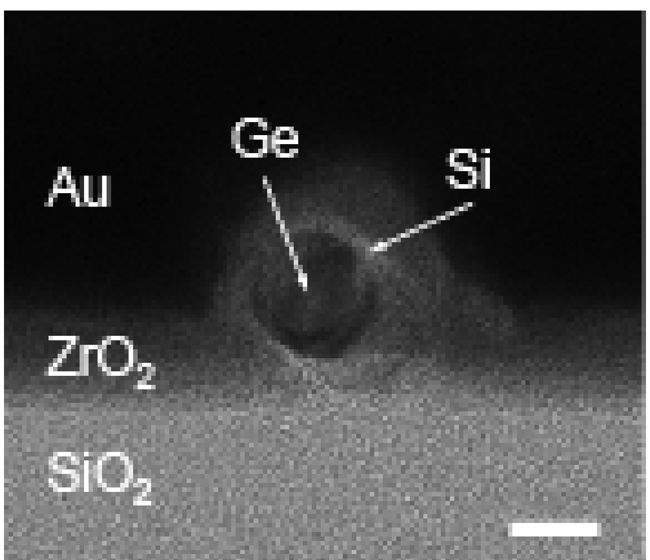


Obtaining the (a) projected image and (b) diffraction pattern of the sample

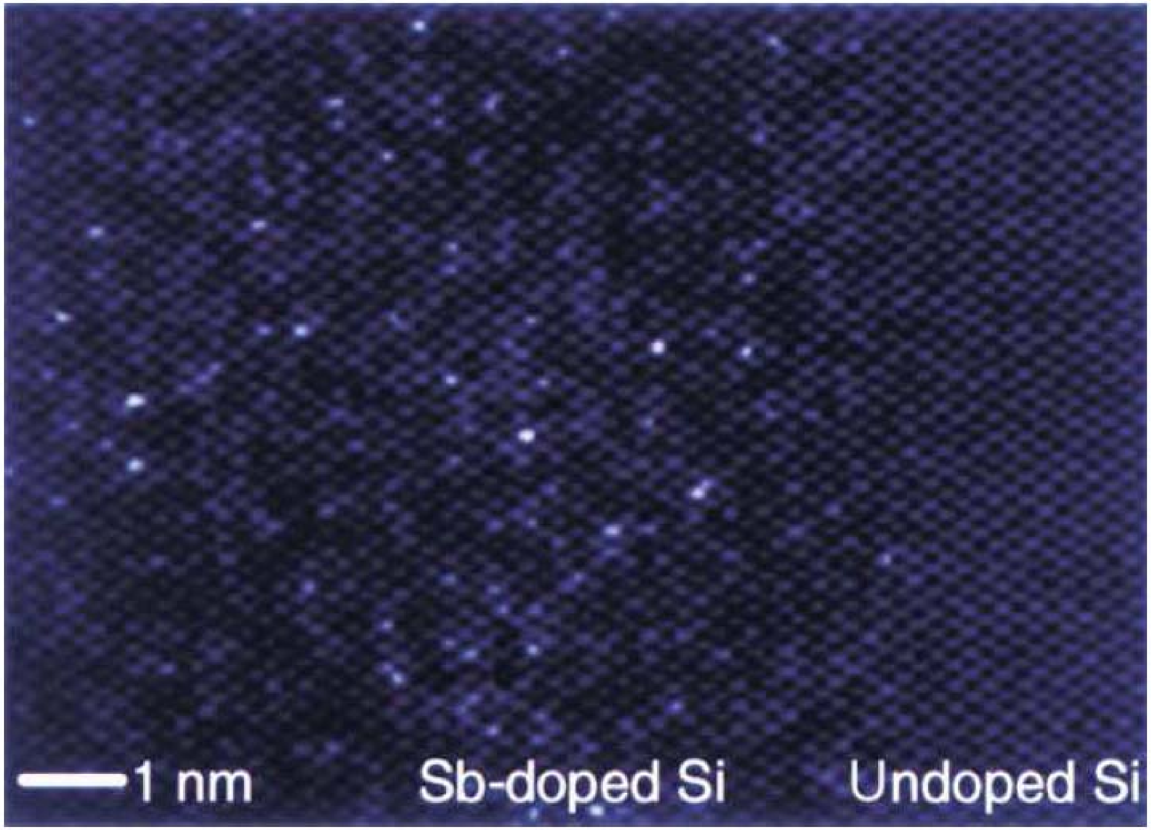
TEM examples







TEM examples



Voyles, P. M. *et al.* *Nature* **416**, 826-829 (2002)

Single dopant study using z-contrast imaging. Ultrathin sample (5nm)

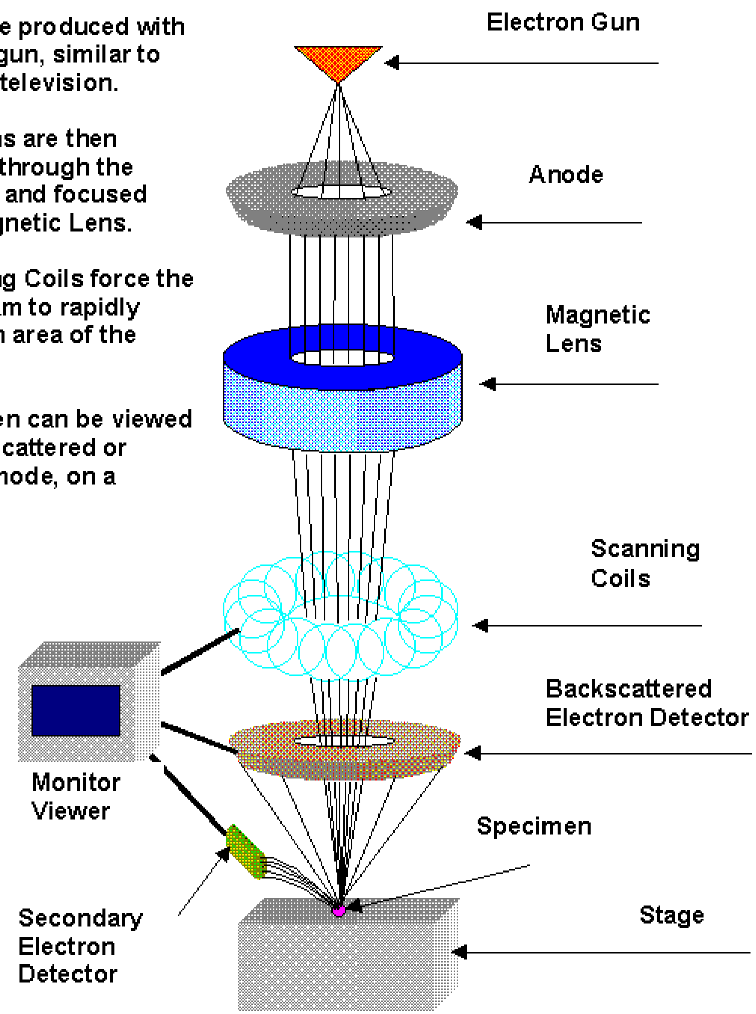
Scanning electron microscope (SEM)

Electrons are produced with an electron gun, similar to the one in a television.

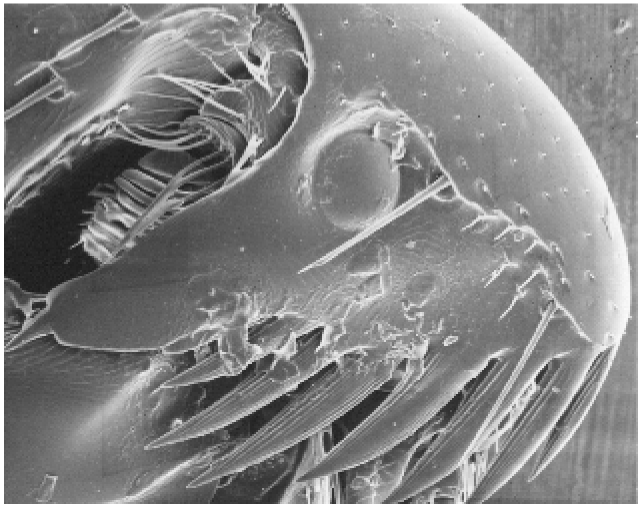
The electrons are then accelerated through the Anode plate and focused with the Magnetic Lens.

The Scanning Coils force the electron beam to rapidly scan over an area of the specimen.

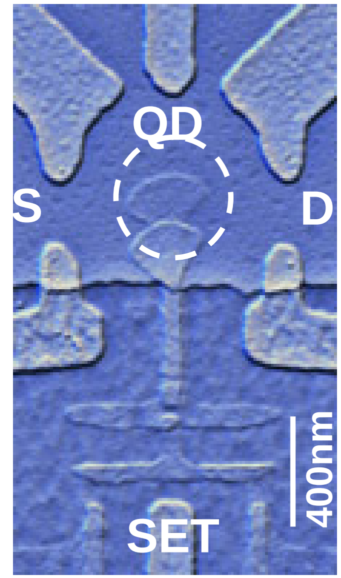
The specimen can be viewed in the Backscattered or Secondary mode, on a monitor.

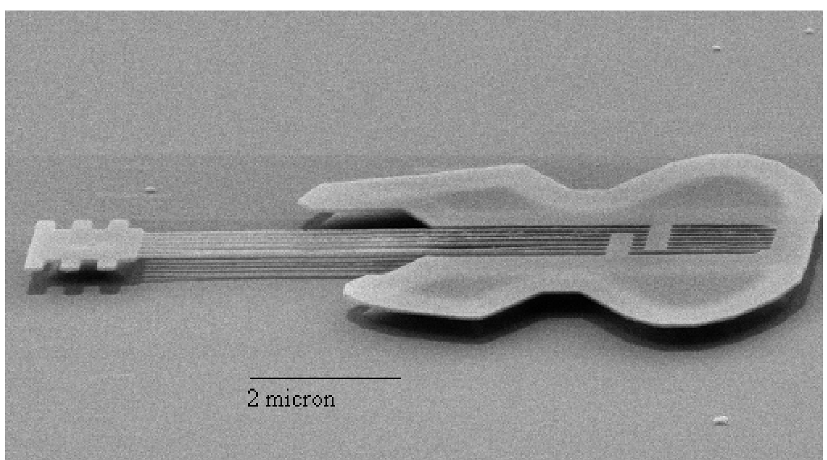


SEM examples



Cat flea, X750





(Device) Fabrication

- Photo lithography
- E-beam lighography
- Nanoimprint lithography

top-down

- Self-assembly
- Direct growth of nanostructures in solution
- Direct growth of nanostructures with CVD

bottom-up

Photolighography

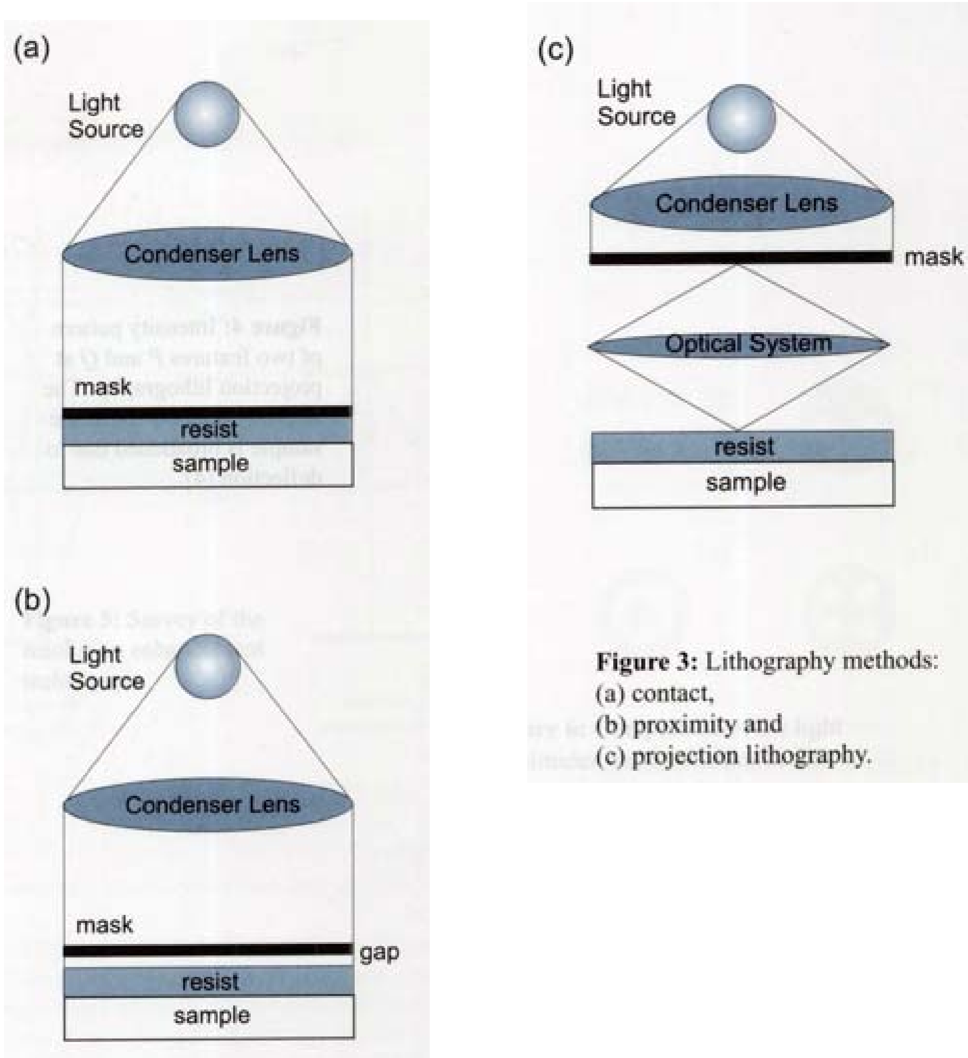
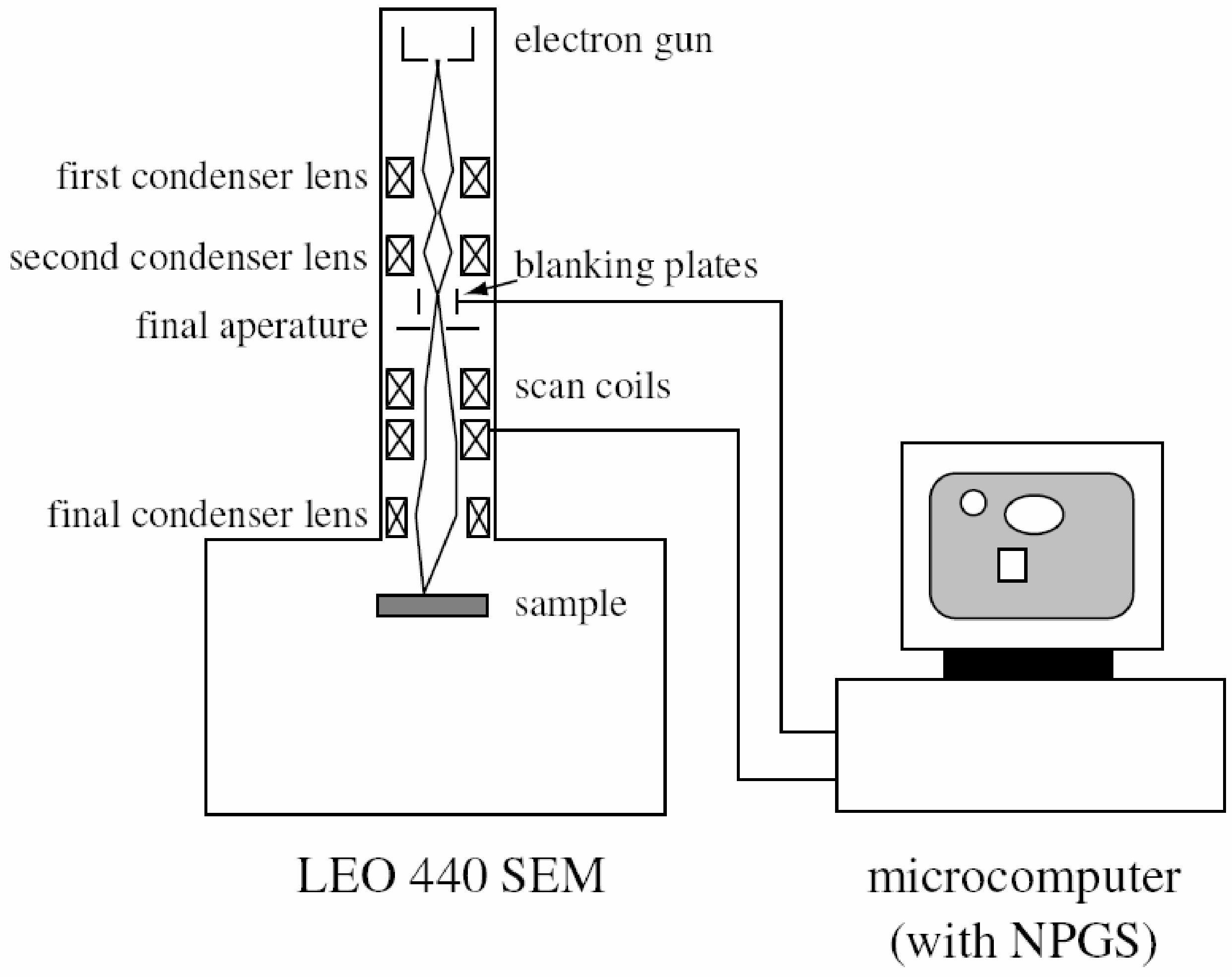
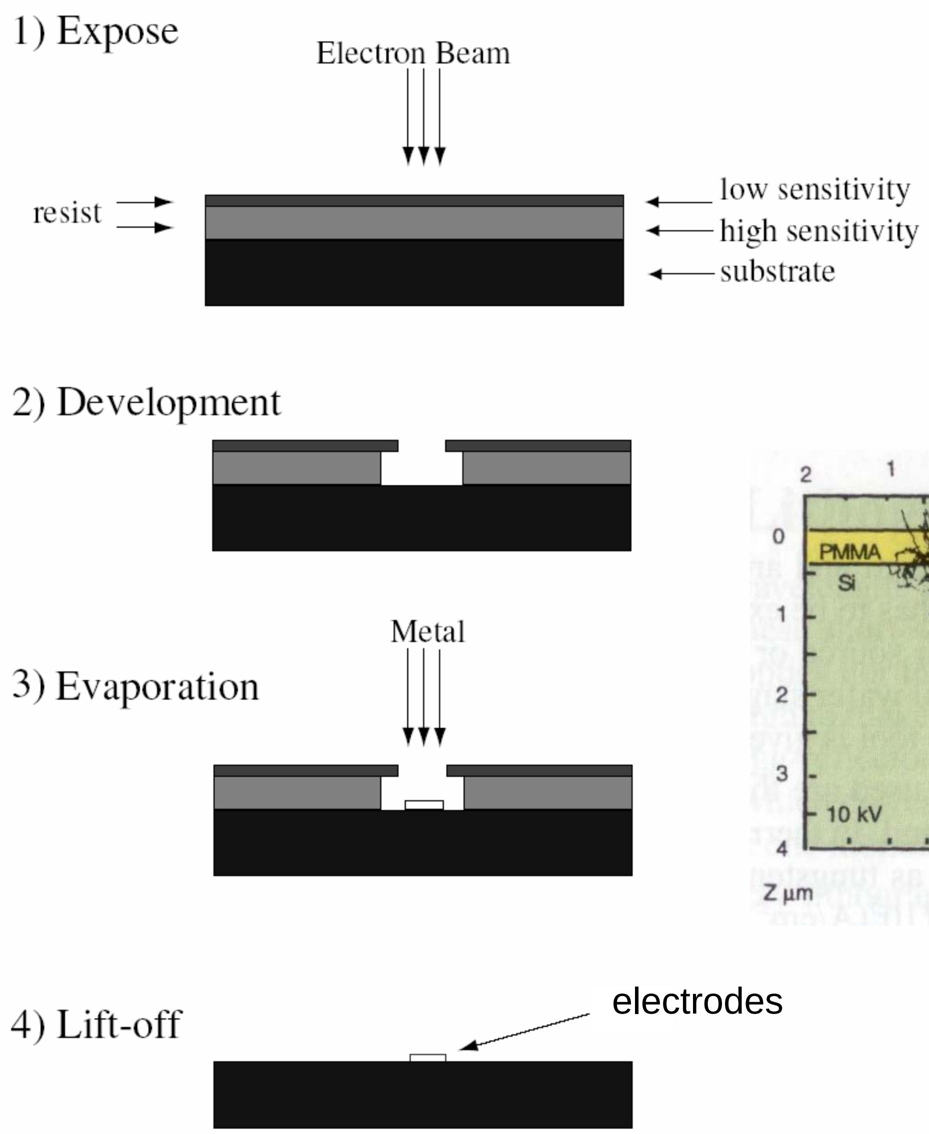


Figure 3: Lithography methods:
(a) contact,
(b) proximity and
(c) projection lithography.

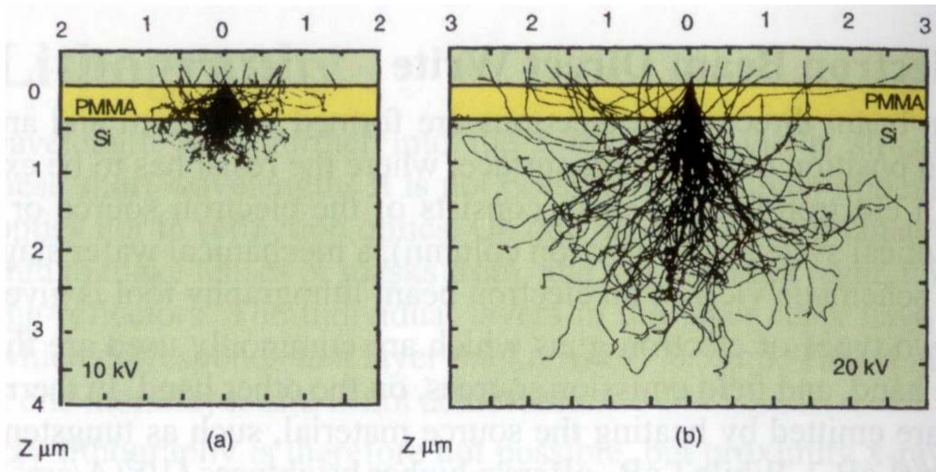
e-beam lithography



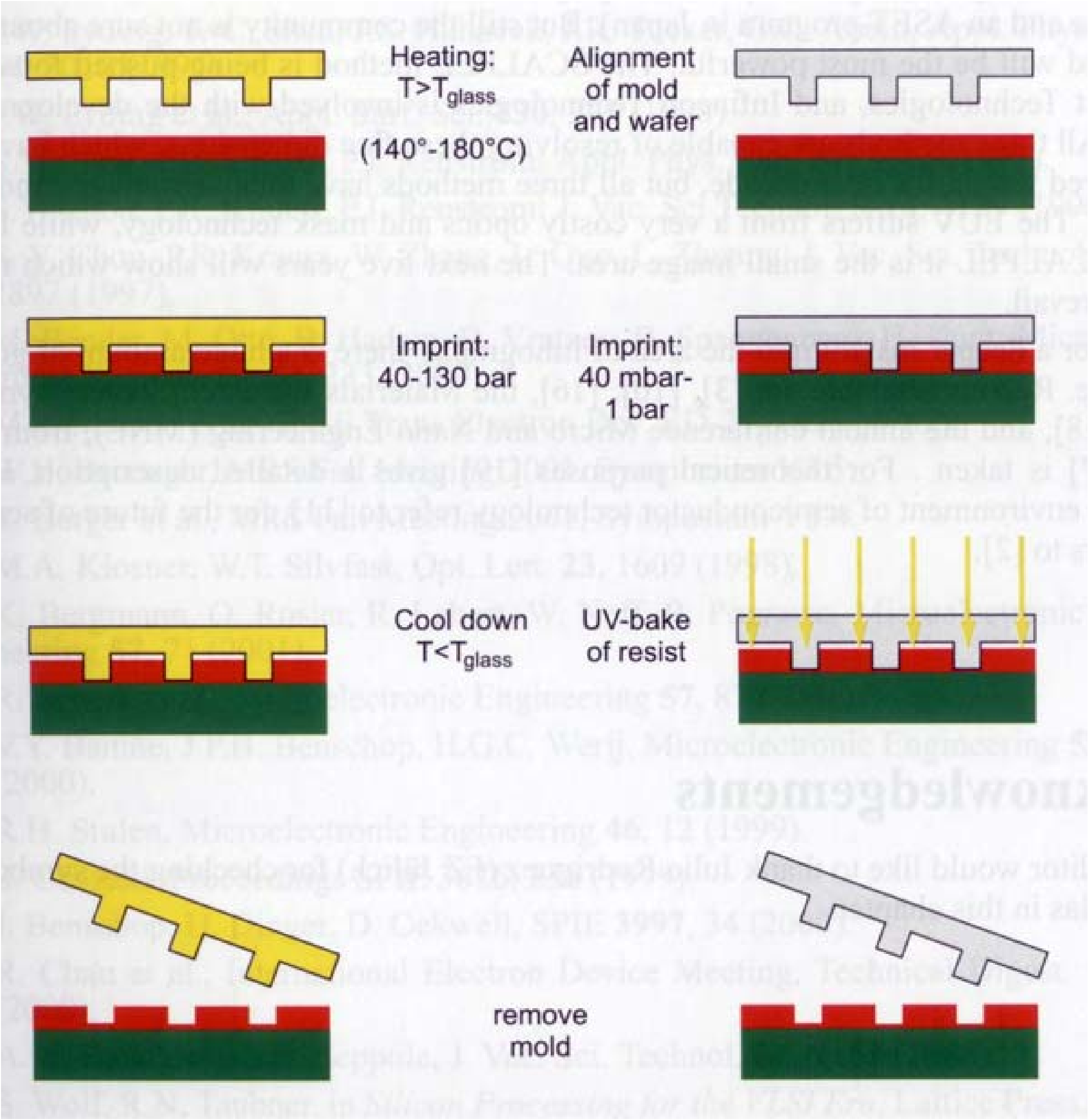
e-beam lithography



Smallest feature size ~20-50 nm, determined by backscattered electrons.
Serial process.

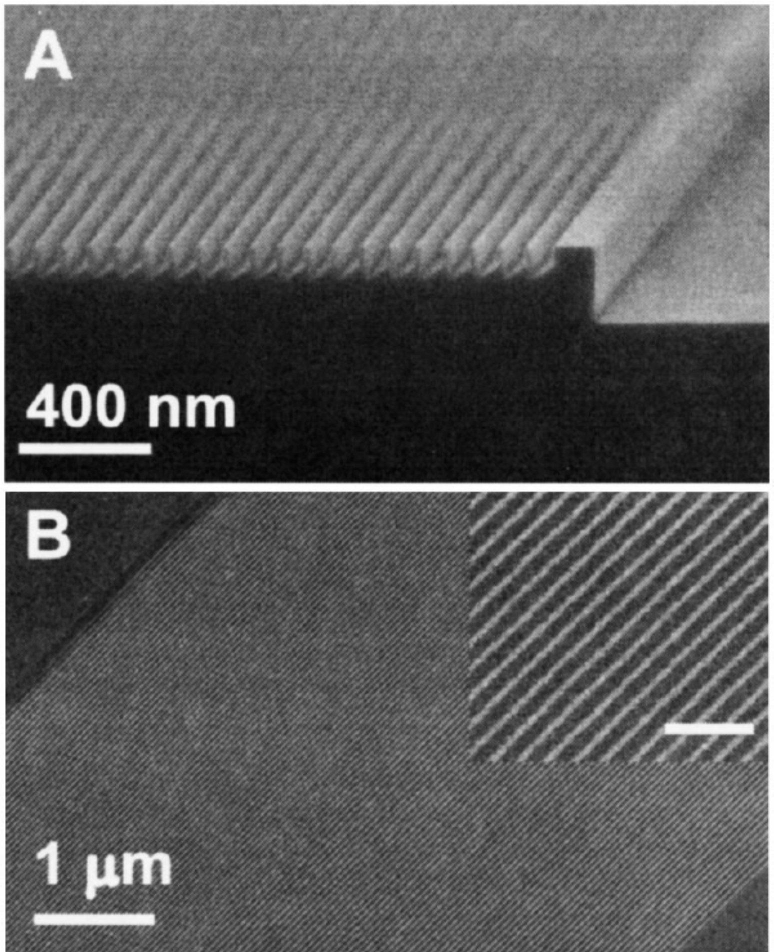


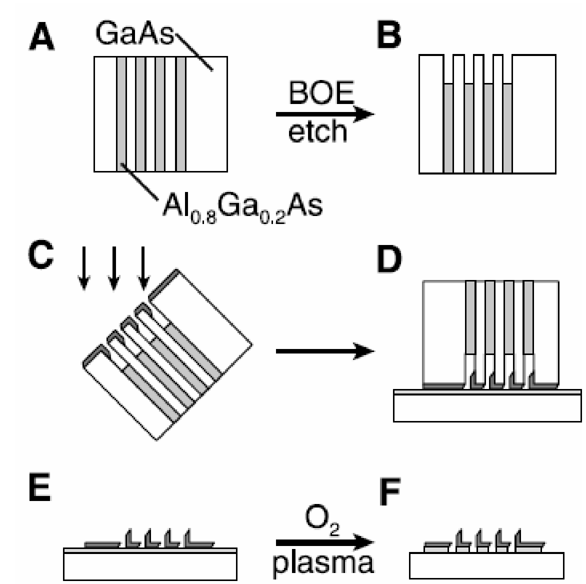
Imprint lithography

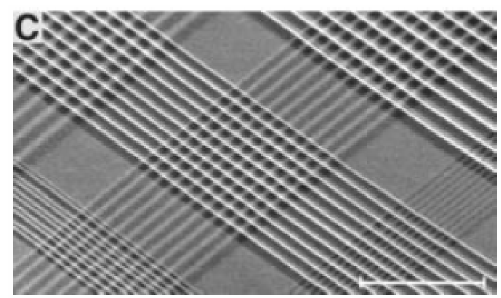


Prof. Guo
EECS

Imprint lithography

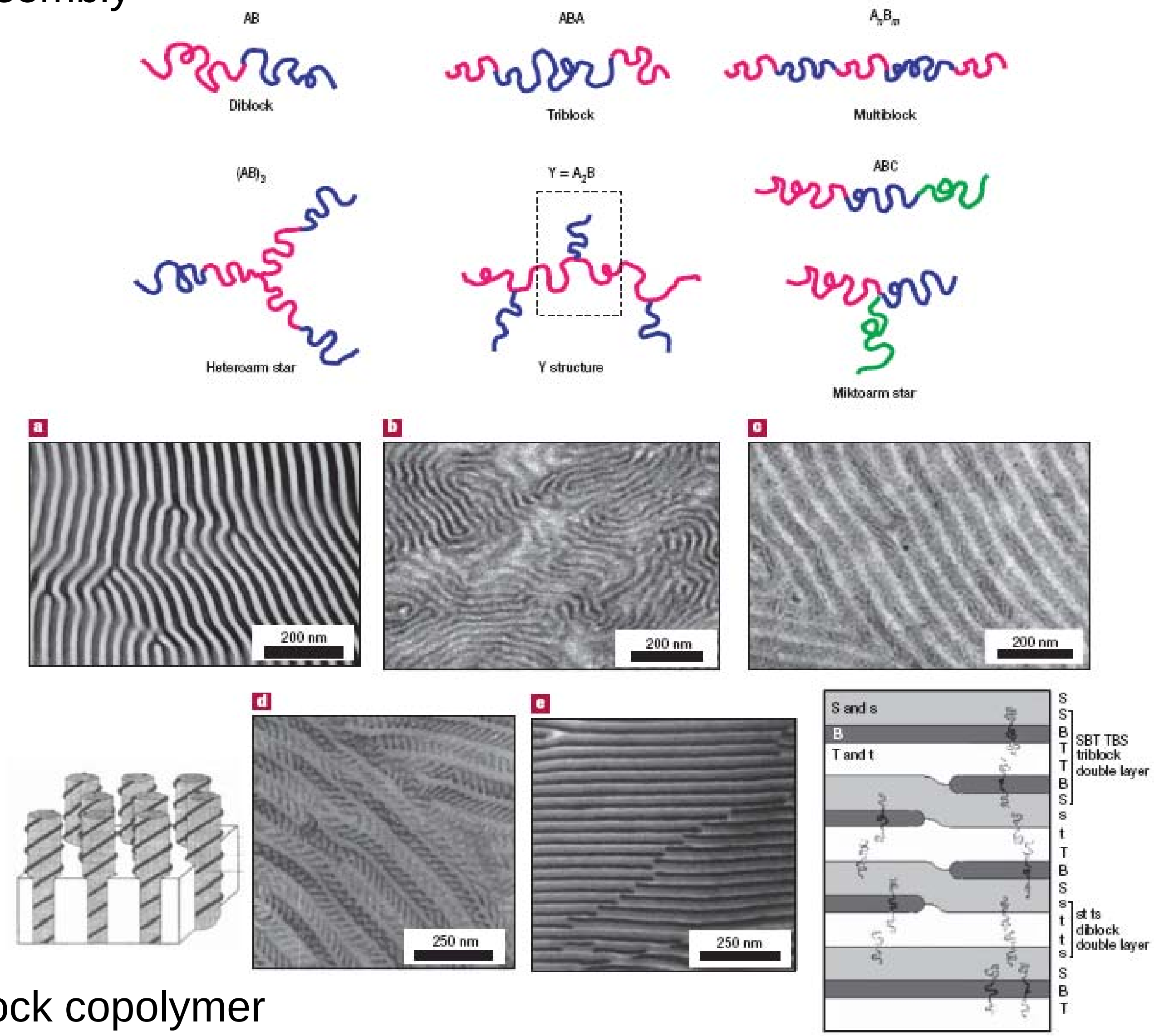






Jim Heath group, Caltech

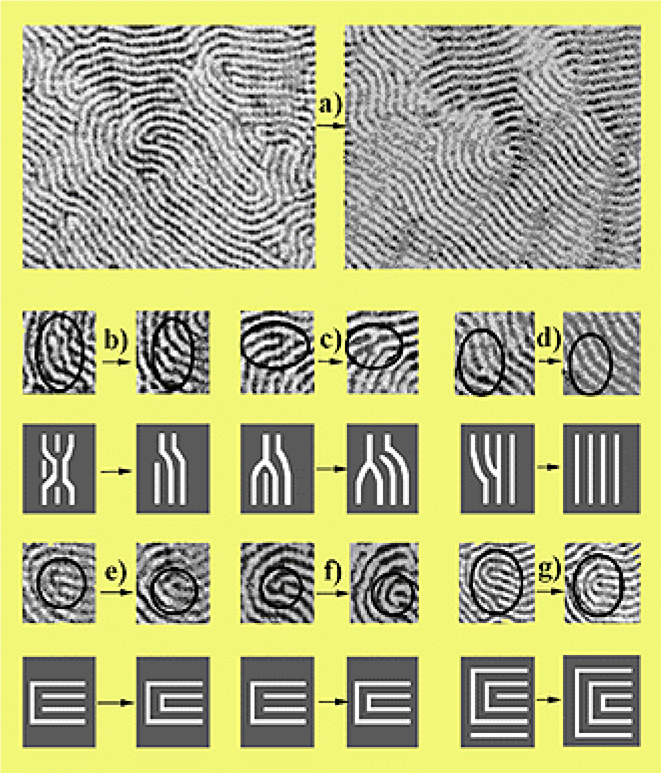
Self-assembly



Diblock copolymer

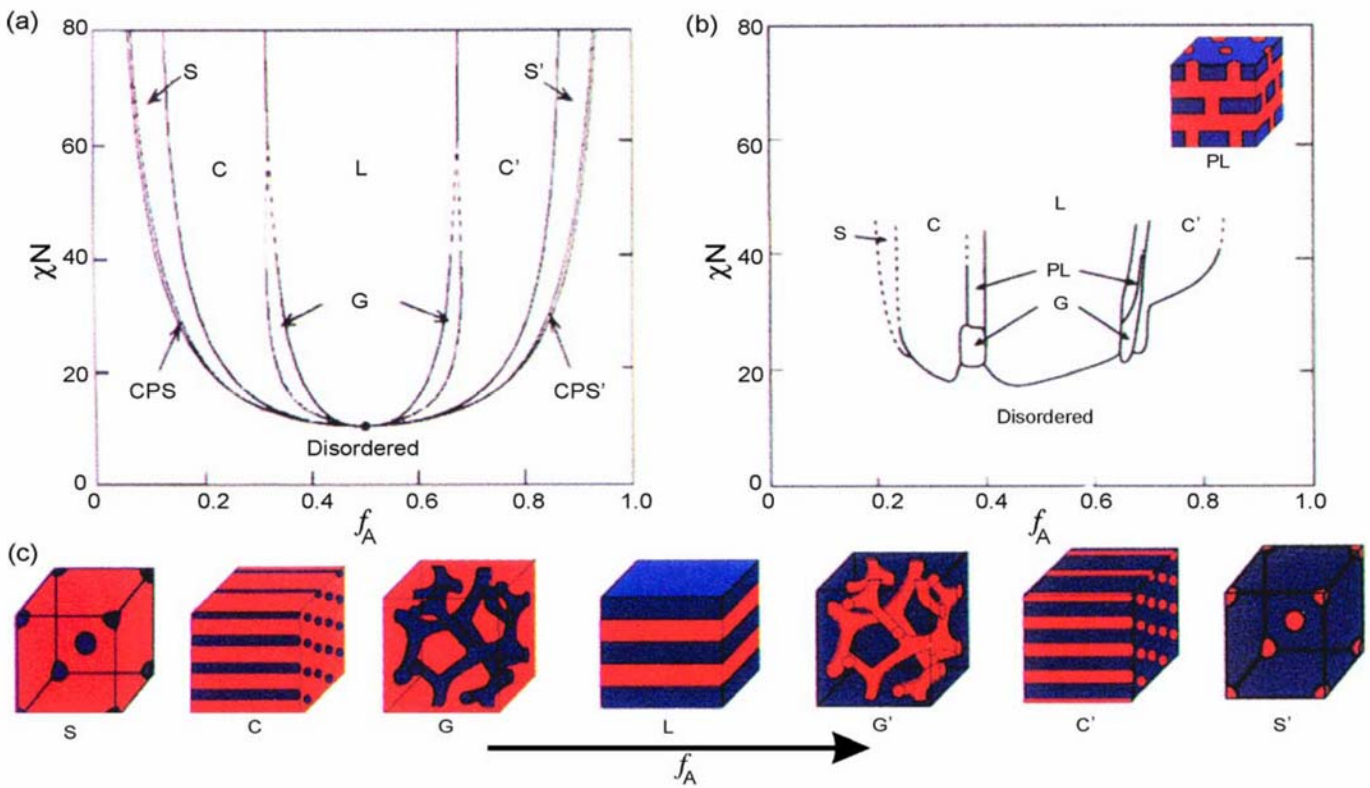
Two chemically distinct polymers mixed together.

Self-assembly



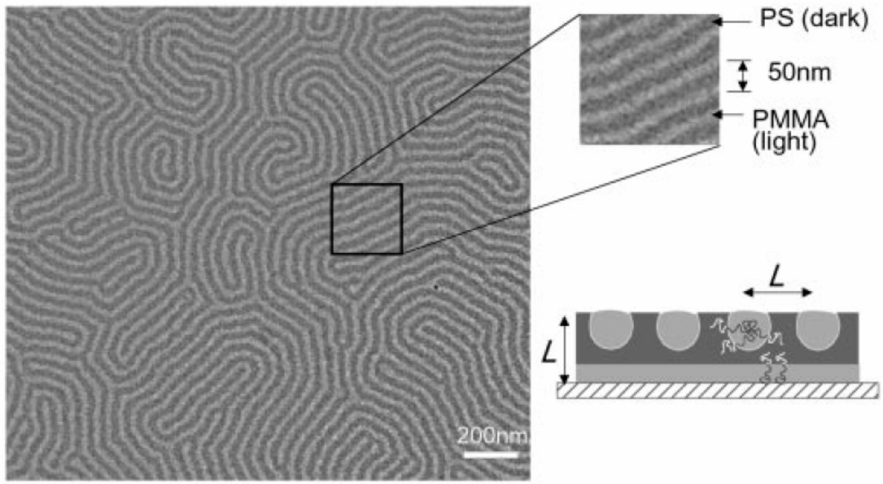
stripe patterns result from repulsion between the two halves of each polymer molecule. Regular pattern developed after annealing since to obtain lower energy.

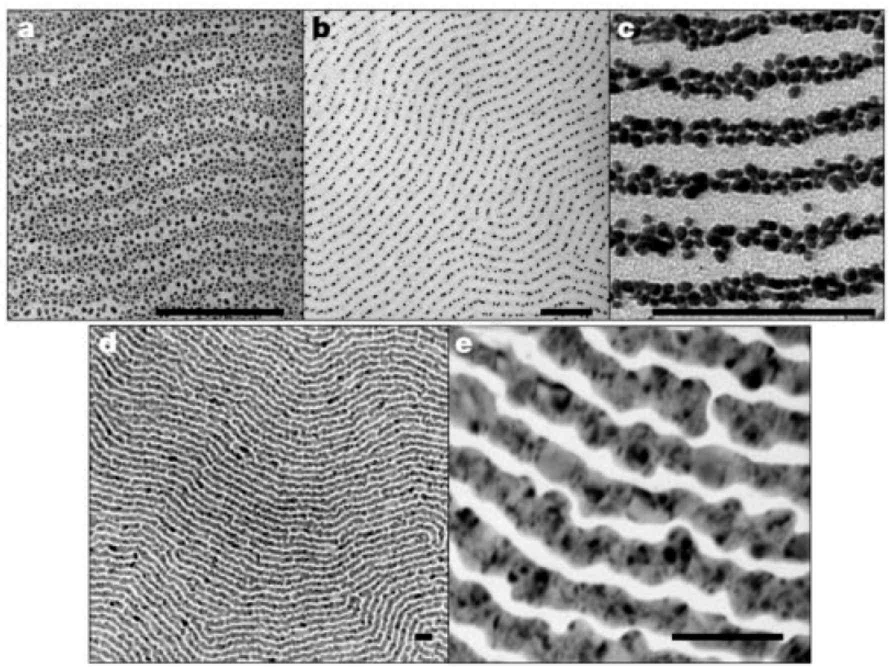
Self-assembly



f: composition

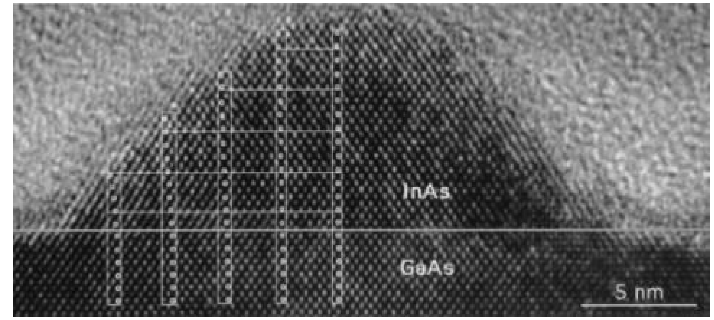
Templated assembly of metal lines

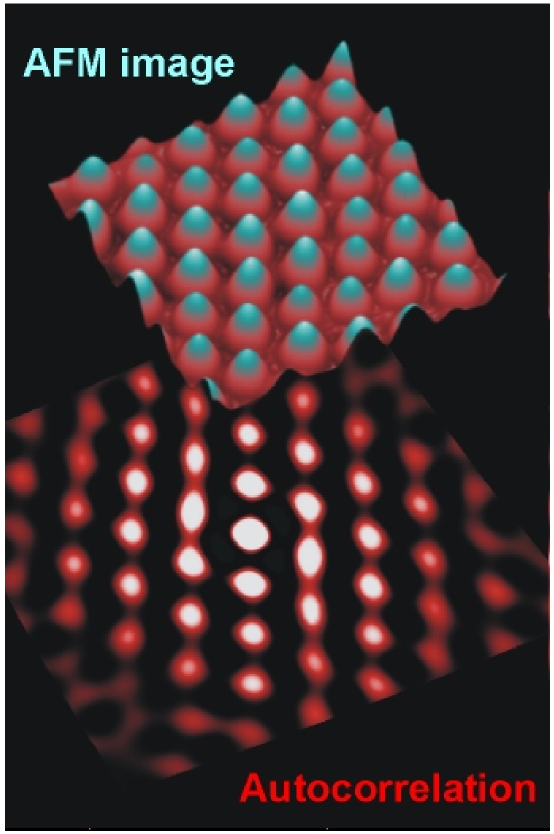


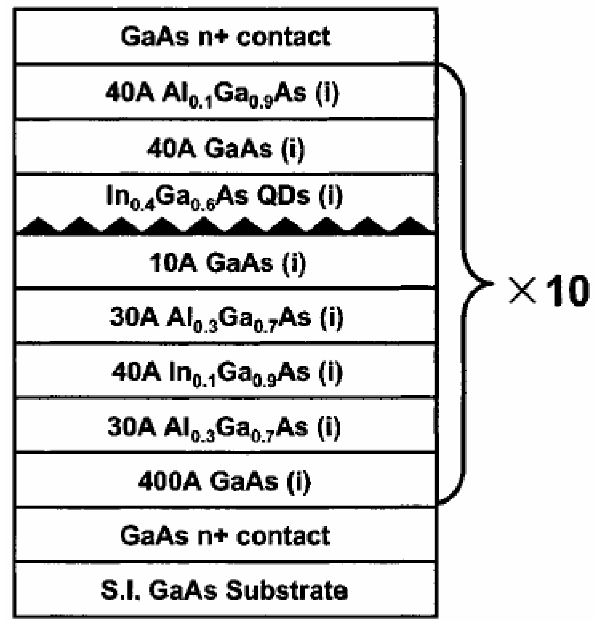


Nature, 414, 735 (2001)

Self Assembly of Semiconductors







InGaAs islands on GaAs

SiGe islands on Si

Prof. Bhattacharya group, EECS

growth: competition between strain energy and surface energy

Self Assembly of Metal Lines

Dysprosium Silicide nanowires on Si

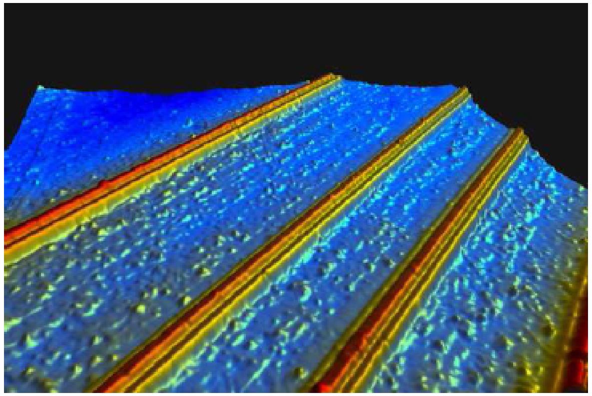
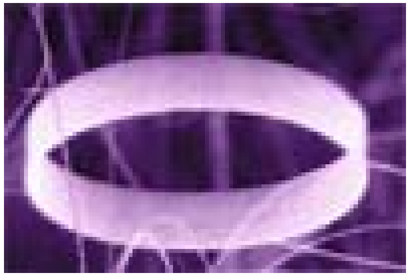
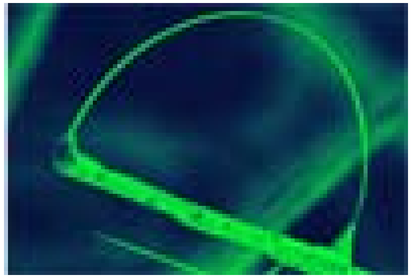
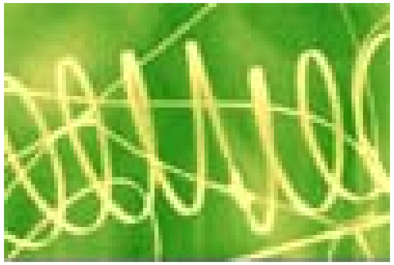


Image from Stan Williams at HP Labs.

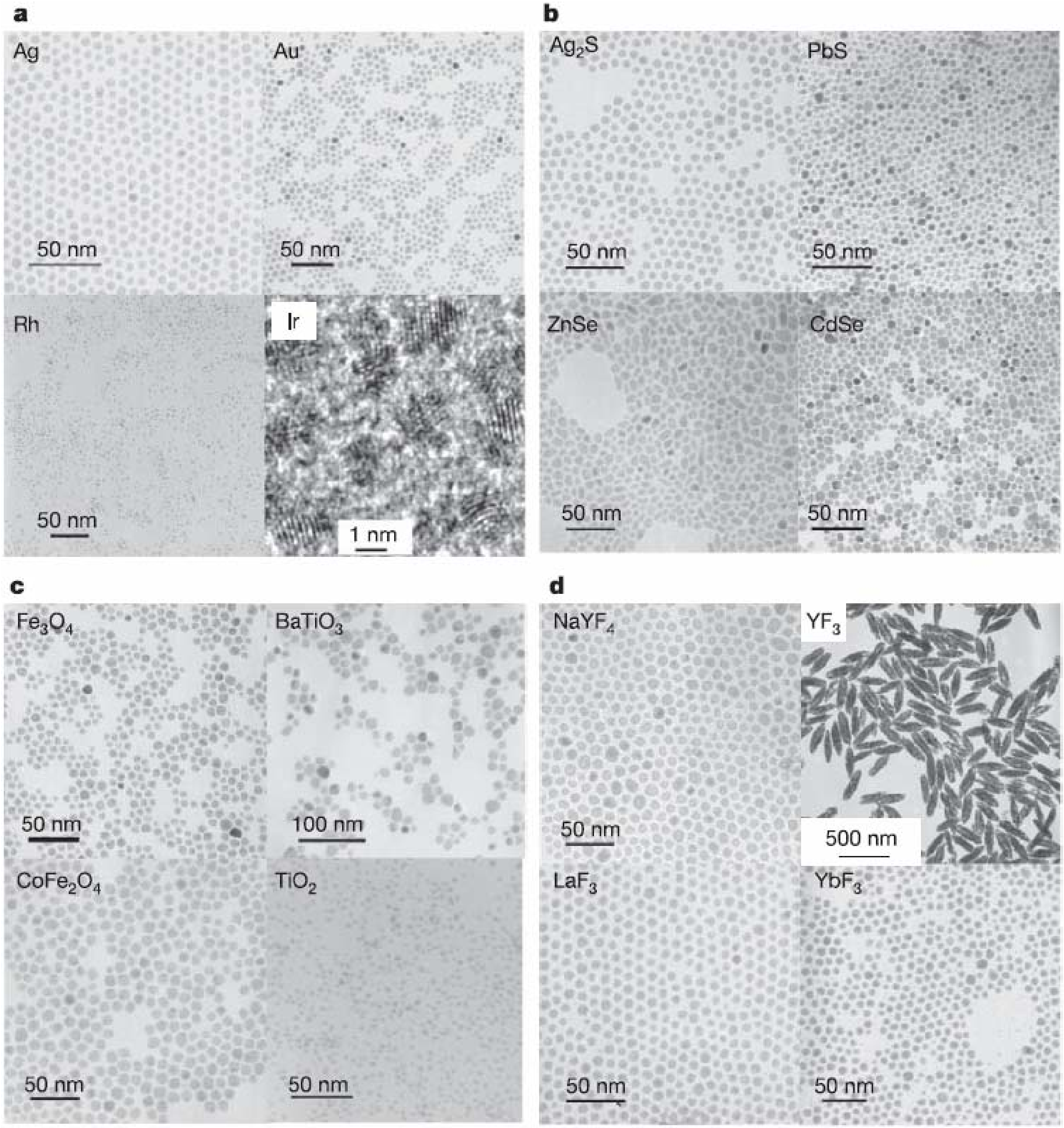
- A giant number of nanostructures is formed in one simple deposition step.
- The synthesized nanostructures can reveal a high uniformity in size and composition.
- They may be covered epitaxially by host material without any crystal or interface defects.

Self assembly of nanostructures

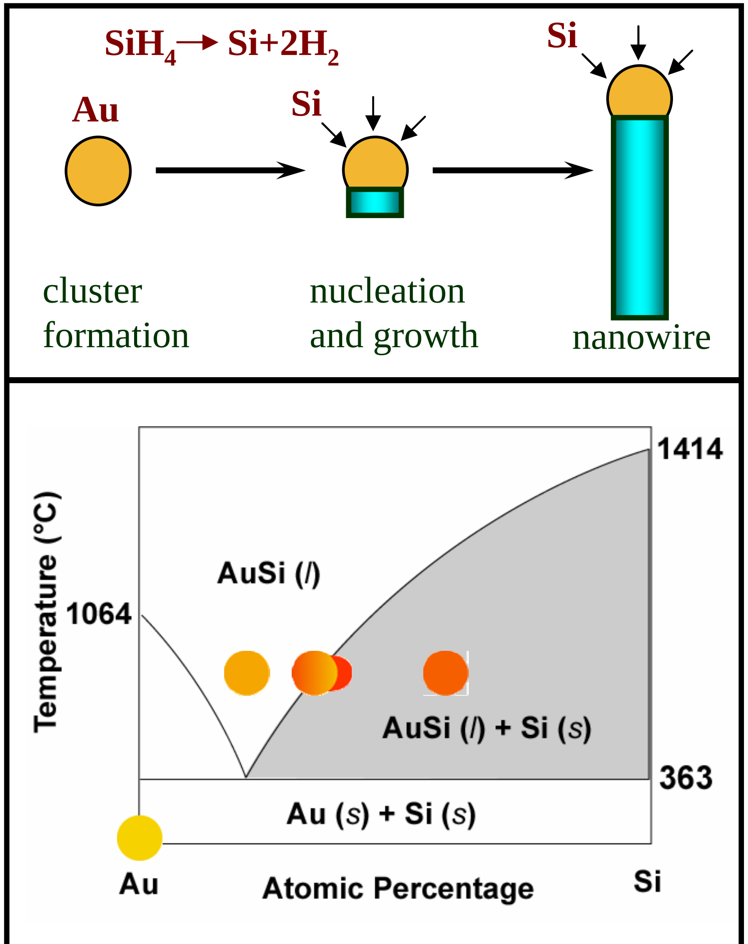
ZL Wang group, Georgia Tech

Grow nanostructures in solution



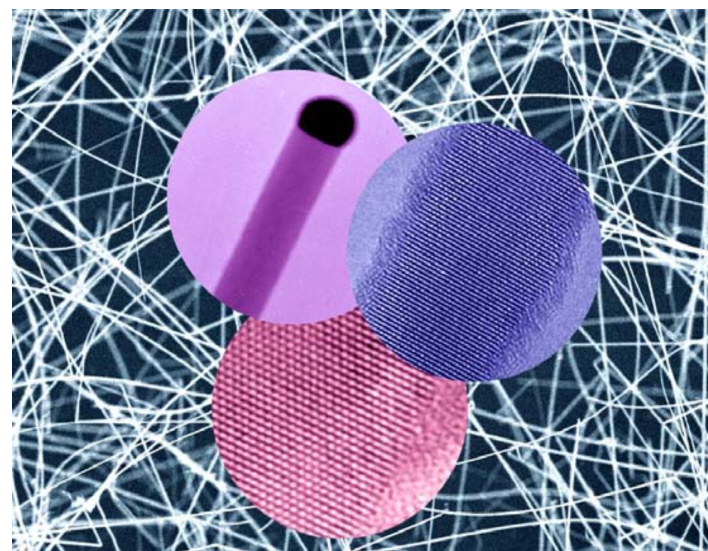
Nature, 437, **121** (2005)

Growth of semiconductor nanowires via catalyst mediated CVD



Vapor-Liquid-Solid (VLS) growth process

- Catalyst mediated CVD process
- Precisely controlled physical dimension (diameter/length)
- Perfect crystalline structure
- Broad range of chemical composition (group IV, III-V, II-VI)



Growth of carbon nanotubes